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**Admitted pro hac vice*

**UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF MONTANA
BUTTE DIVISION**

EVA LIGHTHISER; et al.
Plaintiffs,

v.

DONALD J. TRUMP, in his official
capacity as President of the United
States; et al.
Defendants,

STATE OF MONTANA; et al.
Defendant-Intervenors.

Case No: CV-25-54-BU-DLC

**DECLARATION OF JOHN
PODESTA IN SUPPORT OF
PLAINTIFFS' MOTION FOR
PRELIMINARY INJUNCTION
AND REPLY TO INTERVENOR
DEFENDANTS**

I, John Podesta, hereby declare and if called upon would testify as follows:

1. I am the founder and Chairman of the board of directors of the Center for American Progress (CAP), a distinguished visitor from practice at the Georgetown University Law Center, and a senior fellow at the University of Chicago Institute for Climate & Sustainable Growth where I teach climate policy. I am offering this expert testimony in my personal capacity, and I have personal knowledge of the facts stated herein.

Background and Qualifications

2. Prior to founding CAP in 2003, I served as White House Staff Secretary, Deputy Chief of Staff, and Chief of Staff to President Clinton. During that time, my duties included, among other things, working closely with White House counsel and Office of Legal Counsel on coordinating policy and drafting, processing, and managing the implementation of executive orders, including ensuring their compliance with the Constitution and laws passed by Congress. As Staff Secretary, I was the last check on the form of Executive Orders and consistency with established constitutional principles and legal precedent.

3. From January 2014 until February 2015, I served as Counselor to President Obama. My duties included coordinating the President's climate action plan, where I worked with federal regulatory agencies on efficiency standards, promulgated by the Department of Energy (DOE), and greenhouse gas emissions

standards, promulgated by the Environmental Protection Agency (EPA). In that capacity I also worked closely with the Office of Information and Regulatory Affairs (OIRA) and the Office of Management and Budget (OMB) to ensure the President's directives were well considered and implemented within the bounds of statutory authority.

4. I served on the President's Global Development Council and the UN Secretary General's High-Level Panel of Eminent Persons on the Post-2015 Development Agenda, which included work on climate and energy policy.

5. In 2022, I began serving as a senior advisor to President Biden on clean energy innovation and implementation. Upon the departure of John Kerry as the top U.S. climate diplomat, I assumed the role of coordinating the Administration's international climate and energy policy and was the U.S. Chief representative at the international climate negotiations, COP 29.

6. I have worked closely with seven different directors of OMB in carrying out executive policies and overseeing regulatory efforts in the arena of climate and energy policy. I have also worked with four administrators of the EPA, and numerous other secretaries and administrators across the executive branch over many decades of service. Specifically, I have worked closely with secretaries of Energy, Transportation, Commerce and Interior on climate and energy policies. Across three different presidential administrations, I had lead responsibilities over

White House climate and energy policy. One of my core functions in the White House across administrations was ensuring scientific integrity across federal decision-making, which meant making sure that scientists were insulated from political interference and could render sound judgments that would inform policymaking, even when it was inconvenient.

7. I received my undergraduate degree from Knox College and my law degree from the Georgetown University Law Center. I began my legal career in what was then the Land and Natural Resources Division of the U.S. Department of Justice, now the ENRD, and on the staff of the Senate Judiciary Committee. I have held numerous positions on Capitol Hill, working on bi-partisan legislation, including serving as counselor to Democratic Leader Sen. Thomas A. Daschle (1995-1996). A true and correct copy of my curriculum vitae is attached as Exhibit A.

8. I am submitting this Declaration in support of Plaintiffs' Motion for Preliminary Injunction to enjoin Defendants from implementing several sections of Executive Orders Nos. 14154, 14156, and 14261, which are designed to "unleash" fossil fuels, and block renewable energy such as wind and solar, including by suppressing climate science, dismantling vital federal research programs, and undermining scientific integrity across federal regulatory programs. I am familiar with the parties' filings in the case, the Executive Orders being challenged and related orders, and the many ways the agency and official defendants are

implementing the Orders, some of which I discuss below. I respond below to the Intervenor Defendants' opposition papers that wrongly assert that the balance of equities and public interest favors unleashing fossil fuels, and that no irreparable harm will be done to Plaintiffs or the nation if the Orders stand. I also respond to their mischaracterization of this case compared to another.

9. I am not being paid for any work on this case and am providing my expertise to assist the Court for the benefit of young people, our democracy, and the public interest.

The EOs Are Unconstrained by Law

10. I have significant experience across presidential administrations in working on Executive Orders (EOs) and their implementation. Early in an EO process, if agency heads who will carry out an EO are concerned with the legality of an EO, those concerns would be vetted and resolved by government attorneys including the Department of Justice's Office of Legal Counsel in conjunction with White House Counsel and often the General Counsel of an agency before an EO is even signed by the President. It would be exceptional for an agency to be directed to implement something that was contrary to law, particularly the statutes that govern a particular agency's authority and mandates.

11. However, this administration has altered the ordinary legal review process through another Executive Order 14215, Sec. 7, which directs that "[n]o

employee of the executive branch acting in their official capacity may advance an interpretation of the law as the position of the United States that contravenes the President” That order is at odds with the oath that federal employees take to faithfully execute the law pursuant to the Constitution. By EO 14215, this administration has imposed an explicit loyalty test to the President rather than to the Constitution or the ordinary litmus test of statutory authority. One stark example of this in practice is the whistleblower letter written by 388 EPA employees (174 signing anonymously) documenting the unlawful practices happening at the EPA and pleading with Administrator Zeldin to operate the agency with integrity and in the public interest with fealty to the statutes like the Clean Air Act, rather than the President’s wishes unencumbered by laws.¹ The employees describe policy directives that “undermine the EPA mission of protecting human health and the environment,” “disregard for scientific expertise,” “Dismantling the Office of Research and Development,” and “Promoting a culture of fear” and “trauma”. Pursuant to the President’s directives to unleash fossil fuels and remove any undue burden to the unleashing, EPA employees were being asked to ignore scientific integrity, ignore the cost-benefits of its action, ignore the statutes that not only give it authority to act but also constrain its authority to act in a way inconsistent with human health and welfare. Since January 20, 2025, EPA has been directed to

¹ Doc. 38-4 Ex. G (EPA employees’ letter).

rubberstamp the administration's policy preferences with total disregard to irrefutable climate science. While there can be different policy options available to any president, EPA is required to formulate and carry out policy options that are shaped consistent with the best available science.

12. In response to the EPA employees' letter to their leader, 144 of the named signatories were immediately put on administrative leave and their agency opened an investigation into their decision to sign the letter.² In all of my years in the federal government, I have never seen the kinds of open threats to career agency professionals and scientists that we are witnessing today. That type of intimidation and intolerance of dissent and scientific integrity, which has become a regular practice of this administration, combined with EO 14215, will predictably erode any check within the executive branch on unlawful or unconstitutional executive, administrative, or secretarial orders.

OMB and OIRA Have Significant Control

13. No major federal policy coming out of the Executive branch, including an executive order, is cleared without first being routed through OMB. Among other things, OMB reviews drafts of proposed and final regulations/orders for both consistency with law and to ensure the underlying analysis was done with adequate

² Doc. 38-4 Ex. H (reporting on the administrative leave).

attention to costs and benefits. OMB and OIRA oversee the implementation of the EOs challenged in this case.

14. Based on my experience working with past directors of OMB and administrators of OIRA and understanding the influence of those offices within the White House, it is my expert opinion that OMB Director Russell Vought and OIRA Administrator Jeffrey Clark have significant power over the development and implementation of the challenged EOs here. Specifically, EO 14154, section 3, provides the primary mechanism of control in directing the head of each agency to begin implementing plans to “suspend, revise, or rescind all agency actions identified as unduly burdensome” to unleashing fossil fuels.

15. Under Vought’s and Clark’s direction, however, OMB and OIRA have abandoned their responsibility to vet the challenged EOs for consistency with legal principles and have failed to require a cost-benefit analysis—which are the means by which the public’s interest is protected. If they had fulfilled these responsibilities, it would have been abundantly clear that the challenged EOs are ultra vires, unconstitutional, and promote polluting, comparatively expensive fossil fuel over cheaper, cleaner alternatives. These EOs, under Vought’s direction, require starting from the conclusion that fossil fuels will be unleashed and working backwards to develop the supporting analysis.

16. The EPA letter I reference above, Doc. 38-4 Ex. G, partially quotes what Director Vought has publicly and openly admitted: “*We want the bureaucrats to be traumatically affected. When they wake up in the morning, we want them to not want to go to work because they are increasingly viewed as the villains. We want their funding to be shut down so that the EPA can’t do all of the rules against our energy industry because they have no bandwidth financially to do so. . . . We want to put them in trauma.*”³

17. In my opinion, Director Vought is the key orchestrator of the EOs and their implementation and has deliberately chosen to ignore the Constitution and the statutes governing agency duties, and is instead carrying out a campaign to debilitate agencies like EPA, by cutting funding, terrorizing staff, and cutting climate science programs, to end regulations limiting pollution from fossil fuels. To cite one example among many, the elimination of the staff and office necessary to prepare the Congressionally-mandated National Climate Assessment shows how willing Defendants are to ignore their obligation to fulfill executive orders *lawfully*.⁴ The only options for an agency employee right now is to violate the law, quit, or be fired.

³ Environmental Protection Network, *Facts: The Trump Administration Wants to Traumatize EPA Staff*, <https://www.environmentalprotectionnetwork.org/epafacts/the-trump-administration-wants-to-traumatize-epa-staff/> (last visited Sept. 10, 2025).

⁴ Doc. 25-25 Exs. WW, XX.

Defendants Cannot “Unleash” Fossil Fuels Without Unlawfully Dismantling Climate Science

18. In their brief, the State Intervenor state in part: “[I]t is, at best, highly speculative whether the use of Plaintiffs’ preferred terminology or the wider dissemination of certain research would cause any GHG emitters to materially reduce their emission levels, let alone a critical mass of emitters sufficient to appreciably impact global GHG levels.”⁵ But the EOs are not merely targeting “Plaintiffs’ preferred terminology” or “certain research”. They are targeting climate science itself.

19. I spent much of my career working to ensure scientific integrity in federal decision-making and it is my opinion that what is occurring as a result of these EOs in the field of climate science is the opposite of scientific integrity. Undermining climate science is critical to the EOs’ objective of promoting fossil fuels at the expense of renewable substitutes and Plaintiffs’ health and well-being. That is because reliable science—i.e., research based on established methodologies and vetted via the peer review process—shows greenhouse gas emissions caused by the development and combustion of fossil fuel are driving climate change and costing tens of thousands of lives per year in the U.S. alone, in addition to harmful impacts on health, and the U.S. economy. A mountain of scientific evidence

⁵ Doc. 54 at 6 (Intervenor Opposition).

indicates that global warming and effects of carbon pollution are having negative effects on public health and well-being, including the health and well-being of Plaintiffs.

20. The willful blindness to credible climate science while replacing it with unreliable, non-peer-reviewed reports, is one of the harmful components and direct results of the implementation of these EOs. These agency defendants cannot make the regulatory and policy decisions they are making in the face of the science and so they must rid themselves of it, just as Director Vought recommended in his chapter of the Heritage Foundation’s Project 2025, where he explicitly called for unwinding the US Global Change Research Program and other climate change research because they “reduced the scope of legally proper options in presidential decision-making and in agency rulemakings and adjudications.”⁶

21. Just as cigarette manufacturers touted false theories to challenge scientific consensus regarding the dangers of smoking, Defendants are promoting false theories to promote the “unleashing” of fossil fuel—for example, in a July 29, 2025, report released by the Department of Energy, entitled *A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate*, which was authored by five people selected by Energy Secretary Wright. The purpose of that report is to

⁶ Mandate for Leadership 2025, The Conservative Promise, Project 2025, at 59, https://static.heritage.org/project2025/2025_MandateForLeadership_FULL.pdf.

ignore a mountain of peer reviewed science and tilt the policy making in the direction of fossil fuels. DOE explicitly states it published the report “as part of the U.S. Environmental Protection Agency’s (EPA) proposed rule repealing the 2009 Endangerment Finding. EPA’s proposed rule, if finalized, will mark a critical step forward in achieving President Trump’s commitment to unleash American energy dominance.”⁷ Unlike the cigarette manufacturers, which are private-sector corporations, Defendants are wielding their enormous public power to unlawfully suppress science that contravenes their preferred outcome. By commanding agencies to “unleash” fossil fuel at the expense of Plaintiffs’ well-being and public health, EOs are committed to driving the promotion of falsehoods and the suppression of truth.

22. On August 30, 2025, in response to the DOE’s request for public comments on the DOE Report, Drs. Andrew Dessler and Robert Kopp submitted a compendium of public comments on the DOE report on behalf of more than 85 experts. A true and correct copy of the experts’ comment is attached hereto as Exhibit B.⁸ In the cover letter to their comments, Drs. Dessler and Kopp state: “the

⁷ DOE, *Department of Energy Issues Report Evaluating Impact of Greenhouse Gasses on U.S. Climate, Invites Public Comment* (July 29, 2025), <https://www.energy.gov/articles/department-energy-issues-report-evaluating-impact-greenhouse-gasses-us-climate-invites>.

⁸ Andrew E. Dessler & Robert E. Kopp, *Re: A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate*, Docket ID No. DOE-HQ-2025-0207 (August 30, 2025) (available at

[DOE] CWG report currently fails to adequately represent the scientific understanding of climate change. DOE must subject the CWG report to unbiased, robust, and transparent peer review under the Information Quality Act and other federal requirements. Accordingly, it will require very substantial revision before it can be relied upon by any federal agency or other entity.” *Id.*

23. Pursuant to the EOs, Defendants have politicized what is really a matter of factual analysis with regard to public health and safety. No one in the Federal Government can render an honest judgment about proposed rules, regulations, and policy when the EOs push every energy-related decision toward fossil fuel sources. For example, even when utilities want to shut down coal-fired power plants, the Administration is ordering them not to do so on the basis of the EOs, such as in the case of the Campbell coal-fired power plant in Michigan that was ordered in May to remain open until August 21, which was extended again until November 19.⁹ In this way, federal agencies are directing utilities to ignore what is in the best interests of the utilities’ own ratepayers and shareholders.

24. Likewise, the Department of Energy is targeting efficiency standards for elimination.¹⁰ For decades, Administrations on a bipartisan basis have worked

<https://drive.google.com/file/d/1PwAR8I9YYmPhbQ6CRekHkroJGMbjbX7l/view>
).

⁹ Attached hereto as Exhibits C and D are true and correct copies of DOE’s Order No. 202-25-3 and Order No. 202-25-7 regarding the Campbell coal plant.

¹⁰ Doc. 25-20 Ex. B.

on efficiency standards at DOE in order to reduce the demand for energy, and thereby reduce pollution from fossil fuel generation, and to save consumers money by having appliances available that consumed less energy. If you've declared a "national energy emergency" and claim to care about cheap and abundant energy, you want *more* efficiency out of products being brought to market, not less. Eliminating efficiency standards is completely contrary to that objective. Yet the EOs are directing just that.

25. In my opinion, having spent almost my entire career working at the highest levels of the Executive Branch, the dismantling of climate science and promotion of false "facts" are the most unprecedented and disturbing aspects of the EOs. The dismantling of climate science programs the federal government is responsible for, will have profound effects on the lives and wellbeing of these Plaintiffs, as neutral, science-based government decision-making erodes, warning systems are dismantled, and the information Plaintiffs once had access to disappears. Even more insidious is the public information being communicated by the agencies. If DOE and EPA falsely tell the public that climate change is not a bad thing and not to worry about fossil fuel pollution, or that windmills and solar are bad for them and unreliable energy, that false information erodes the knowledge of an educated citizenry and the ability of the political process to function to address this national and global crisis.

Defendants Cannot “Unleash” Fossil Fuels Without Unlawfully Rescinding the Endangerment Finding

26. In directing the federal government to “unleash” fossil fuels, Defendants are pursuing their stated objective to deregulate the fossil fuel industry. For instance, pursuant to the EOs, Defendants are in the process of rescinding rules that set emission limits on internal combustion engine vehicles. Rescinding the Endangerment Finding, which constitutes an official EPA scientific finding that greenhouse gases are air pollution endangering human health and welfare, is central to that process.¹¹ In my opinion, that is why the EOs direct EPA to reconsider the Endangerment Finding. The President’s energy policies expressed in the EOs challenged here cannot be accomplished fully without rescinding the Endangerment Finding. That scientific finding is foundational. Nor can the EOs be complied with if EPA does not rescind the Endangerment Finding. EPA is thus in the position of ignoring its statutory duty and the Constitution, or ignoring the EOs.

27. In my opinion, rescinding the Endangerment Finding will cause the Plaintiffs profound harm that is very difficult to reverse. These young people still have most of their lives to live, and the EOs are burdening them with enormous

¹¹ Attached as Exhibit E hereto is a true and correct copy of EPA’s Reconsideration of 2009 Endangerment Finding and Greenhouse Gas Vehicle Standards, 90 Fed Reg. 36288 (Aug. 1, 2025).

amounts of greenhouse gas pollution that would not otherwise be emitted—and thus climate change injuries they would not otherwise have experienced.

28. I remained in the White House until the most recent transition of power took place and I oversaw federal climate policy. At no point in time was I or any agency aware of any reasonable or legitimate basis for rescinding the Endangerment Finding. If anything, as climate change has worsened, as extreme weather events attributed to climate change have caused demonstrable damage to public health, welfare and the economy, and the scientific community has conducted more research and gained even greater understandings of the climate system and the effects of fossil fuel pollution, the basis for the Endangerment Finding has only grown.

29. Ultimately, the Defendants want to kick out the foundation so they can let the whole regulatory framework collapse, ignoring the consequences, which are profoundly negative for these Plaintiffs and the health and welfare of the American people.

The EOs Target a Non-Existent “Green New Deal” to Justify Their Broad-Based Attack on Climate and Environmental Protections

30. Section 7 of EO 14154 directs the Defendant agencies and officials to terminate the “Green New Deal.” But there is no federal policy, regulation, or plan called the Green New Deal. Defendants’ statement is based on a false premise designed to support Defendants’ broad-based attack on climate and environmental protections, including the targeting of funding programs Congress established to

incentivize the substitution of cleaner renewable energy for fossil fuel and electric vehicles for internal combustion engine vehicles.

31. These funding programs have been relied upon by states, businesses, families, schools, and community organizations across the United States, including in Plaintiffs' communities. In fulfilling the EOs' command to "unleash" fossil fuel, Defendant Agencies are violating the faithful execution of grants and loans made to promote the substitution of clean energy sources and clean vehicles for polluting infrastructure. Contracts that were honored by Defendants prior to the EOs are now being disregarded at the whim of agency directors. In my opinion, this practice is inconsistent with the proper and lawful response to an unlawful executive order.

The Attack on Electric Vehicles

32. Executive Order 14154, section 2(e), directs Defendants to "eliminate the 'electric vehicle (EV) mandate' and promote true consumer choice" by "removing regulatory barriers" and "terminating" "state emissions waivers that function to limit sales of gasoline-powered automobiles" as well as by eliminating subsidies for electric vehicles.

33. The federal government does not have "an EV mandate," but there are rules promulgated by the EPA and DOT that, taken together, limit tailpipe emissions and promote vehicle efficiency in ways that have proven invaluable for public health. We worked to ensure that the auto industry accepted the rules and could work

with them to create a variety of consumer options at different price points. If such rules are eliminated consistent with the EOs, the net result will be higher greenhouse gas emissions, more climate change, higher life-cycle transportation costs to consumers, and greater harm to Plaintiffs and the public. The agencies I worked with conducted rigorous, science-based analyses, and the consequences of eliminating those rules is clear—pollution will increase.

The Challenged EOs Unlawfully Skew the Market in Favor of Fossil Fuel and Against the Least Expensive, Least Polluting Forms of Energy

34. Executive Order 114156 defines “energy” and “energy resources” without including wind, solar, or battery storage. In my experience, no federal agency prior to January 20, 2025, had ever utilized such a definition. In fact, the Department of Energy has an office of renewable energy just as it has an office of fossil energy. DOE has long viewed wind, solar and storage as reliable sources of energy and the most significant contributor to new generation capacity. There was no basis inside the federal government prior to January 20 and these EOs to refer to renewable energy resources as unreliable.

35. During my years of service in the Federal Government, different administrations expressed different preferences in terms of energy mixes. But I am unaware of any administration ever declaring war on renewable energy the way the second Trump Administration has done. That is truly unprecedented.

36. The Administration's war on renewable energy, via these EOs, is having predictable and substantial consequences. The most reliable, least expensive, and cleanest forms of energy are being taken off the table and rendered far less accessible. As a result, fossil fuels are in the process of becoming the primary sources of energy supported by the Federal Government.

37. Study after study shows that renewable energy is cheaper, safer, and more reliable than fossil fuel—which is why about 93% of new energy generation capacity built in 2024 was carbon-free.¹² The problem is, these agencies cannot freely allow wind and solar and storage and EVs to proceed unencumbered because it would violate these EOs to do so.

Juliana v. United States

38. Finally, Intervenors and the Federal Defendants make factual assertions that the present case is just like *Juliana v. United States*, a case with which I am familiar from my time in the White House. One of my responsibilities in the Biden Administration was to work with the White House Counsel's office to help coordinate the Administration's response to certain cases against the administration, including the *Juliana* case. During my service in the Biden Administration, I was briefed on, familiar with, and involved in the federal response to *Juliana v. United States*. This case—*Lighthiser v. Trump*—is factually not the same case as *Juliana*,

¹² See Doc. 25-6, ¶ 14 (Jacobson Declaration).

as the Intervenor contend. To the contrary, it is different in fundamental respects as to the fact pattern, the conduct challenged, the claims, and importantly, the remedy sought.

39. Factually, ten years ago the *Juliana* plaintiffs alleged that the entirety of federal energy policy over the prior five decades had caused them harm. They sought a remedy that would have compelled a remedial plan to put in place a different federal energy policy. By contrast, in the present case, the allegations of fact state that provisions of three specific Executive Orders issued this year and implemented by various agencies will cause Plaintiffs harm and have already begun to do so. As for the remedy sought, Plaintiffs here request traditional forms of declaratory and injunctive relief with which I am familiar in cases against the Government. These Plaintiffs do not seek any kind of special remedial plan for the Government's failure to redress climate change.

40. What's distinctly different here is Plaintiffs challenge specific executive policies and directives, and agency implementation thereof, that have occurred since January 20 of this year. The challenged Government policies and implementing acts differ substantially from past Government conduct as I've described in detail above.

Conclusion

41. An essential function of a democratic government is to inform the public of the basic facts and threats that they face. The public needs to know what is in store for them regarding more heat, storms, fires, threats to water and food systems, the price of energy, and more. This administration is choosing fossil fuels and their pollution and promoting false facts over the truth. One of our Nation's founders, James Madison, warned our country that "[a] popular Government, without popular information, or a means of acquiring it, is but a Prologue to a Farce or a Tragedy; or, perhaps both."¹³ The disregard of science, the suppression of factual information, the failure to consider the costs to the health and well-being of the American people in the actions being taken are catastrophic given the state of our climate emergency. These EOs endanger Plaintiffs and the public interest, for their increased pollution, their blocking of the deployment of clean and affordable energy solutions, and their assault on the scientific foundation of federal policymaking.

¹³ Letter from James Madison to W.T. Barry (Aug. 4, 1822), in *The Founders' Constitution* (Philip B. Kurland & Ralph Lerner, eds.), "Epilogue: Securing the Republic," doc. 36 (available at <https://press-pubs.uchicago.edu/founders/documents/v1ch18s35.html>).

In accordance with 28 U.S.C. § 1746, I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct.

Executed on September 10, 2025 at Oceanside, California.



John Podesta

EXHIBIT A

John D. Podesta

EDUCATION

BS, Knox College (1971)

JD, Georgetown University Law Center (1976)

EXPERIENCE

- **Georgetown University Law Center**
Distinguished Visitor from Practice (current)
- **University of Chicago Institute for Climate & Sustainable Growth**
Senior Fellow (current)
- **Center for American Progress**
Founder, President, and CEO (2003-2011)
Board Chair (2011-2013, 2017-2022, 2025-present)
- **The White House**
Assistant to the President, Staff Secretary (1993-1995)
Assistant to the President, Deputy Chief of Staff (1997-1998)
Chief of Staff to the President (1998-2001)
Counselor to the President of the United States (2014-2015)
Senior Advisor to the President for Clean Energy Innovation and Implementation and for International Climate Policy (2022-2025)
- **Hillary for America**
Chair (2015-2016)
- **Presidential Transition Team**
Co-Chair (2008-2009).
- **Podesta Associates, Inc.**
President, General Counsel (1988-1993)
- **U.S. Senate Agriculture Committee**
Chief Counsel (1987-1988)
- **U.S. Senate Judiciary Subcommittee**
Chief Minority Counsel (1981-1987)
- **U.S. Senate Judiciary Committee, Washington, DC**
Counsel (1979-1981)
- **ACTION, Washington, DC**
Special Assistant to the Director (1978-1979)
- **U.S. Department of Justice**
Trial Attorney (1976-1977)

Other Positions

- **UN Secretary-General's High-level Panel of Eminent Persons on the Post 2015 Development Agenda**
Member
- **The Constitution Project – Bipartisan Liberty and Security Committee**
Member (2002-2014)
- **Committee on Protecting and Reducing Government Secrecy**

- Member (1995)
- **Administrative Conference of the United States**
Council Member (1993-1995)
- **Task Force on Privacy and Technology**
U.S. Senate Subcommittee Chair (1991)
- **ABA Section on Individual Right and Responsibilities**
Council Member (1994-1997)

SCHOLARSHIP

Books

- John Podesta, *The Power of Progress: How America's Progressives Can (Once Again) Save Our Economy, Our Climate, and Our Country* (New York: Crown Publishing Group 2008)
- John Podesta, *Think Progress: Ten Big Ideas to Change the Country* (New York: Crown Publishing Group 2007)
- William J. Perry, Madeleine K. Albright, Graham T. Allison, Samuel R. Berger, Ashton B. Carter, Wesley K. Clark, Thomas E. Donilon, Michele A. Flournoy, John Podesta, Susan E. Rice, John M. Shalikashvili, Wendy R. Sherman, Elizabeth Sherwood-Randall & James Steinberg, *The U.S. Military: Under Strain and at Risk* (Wash., D.C.: National Security Advisory Group 2006)
- Peter M. Shane, John Podesta & Richard C. Leone, Eds., *A Little Knowledge: Privacy, Security, and Public Information After September 11* (New York: Century Foundation Press 2004)

Selected Contributions to Law Reviews and Other Scholarly Journals

- John Podesta, Interview, *An Interview with John Podesta*, 21 Geo. J. Int'l Aff. 41–43 (2020)
- John Podesta & Peter Ogden, *The Security Implications of Climate Change*, 31 Wash. Q. 115–38 (2008)
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- John Podesta, *The Climate Crisis, Migration, and Refugees*, Brookings Blum Roundtable (2019)
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- John Podesta & Josh Gottheimer, *Civil Rights: Mixed Messages From the Bush Administration*, Hum. Rts., Spring 2001, at 3–6

Book Chapters & Collected Works

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Peter M. Shane, John Podesta & Richard C. Leone, *Introduction*, in *A Little Knowledge: Privacy, Security, and Public Information After September 11*, 1-10 (Peter M. Shane, John Podesta & Richard C. Leone eds., New York: Century Foundation Press 2004)

John Podesta, *Need to Know: Governing in Secret*, in *The War on Our Freedoms: Civil Liberties in an Age of Terrorism* 220-236 (Richard C. Leone & Greg Anrig eds., New York: BBS Public Affairs 2003)

TEACHING EXPERIENCE

- **Georgetown University Law Center**
Distinguished Visiting Professor from Practice
- **Yale University**
Senior Fellow, Jackson Institute,
- **University of Chicago**
Senior Fellow, Institute for Climate and Sustainable Growth,

SELECTED AWARDS

- U.S. Office of Personnel Management, Meritorious Service Award
- U.S. Department of the Army, Award for Distinguished Civilian Service
- Federal Republic of Germany, Commander's Cross of the Order of Merit
- Georgetown University Law Center, Robert F. Drinan, S.J., Law Alumni Public Service Award
- Wilderness Society, Ansel Adams Award

HONORARY DEGREES

- Honorary Doctor of Laws, Knox College, 1998
- Honorary Doctor of Humane Letters, Hellenic American University 2010

BAR MEMBERSHIP

- District of Columbia

EXHIBIT B

August 30, 2025

Chris Wright, Secretary
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

**Re: A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S.
Climate, Docket ID No. DOE-HQ-2025-0207**

Dear Secretary Wright:

On behalf of the more than 85 experts who contributed to the *Climate Experts' Review of the DOE Climate Working Group Report*, we are writing to submit this compendium of public comments on the Climate Working Group (CWG) Report entitled *A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate*, under docket number DOE-HQ-2035-0207.

This compendium begins with a Summary for Policy Makers that highlights a selection of key points from across the constituent Comments. It then contains 48 distinct Comments, each of which makes a variety of points regarding different elements of the CWG report and the report as a whole. Authorship of each Comment is separately noted. It concludes with biographical sketches providing the authors' credentials.

We hope the Summary for Policy Makers and the 48 Comments will be given full consideration and that, as with public comments on National Climate Assessments, there will be a substantive response to each and every element of these comments.

As explained at length in these comments, the CWG report currently fails to adequately represent the scientific understanding of climate change. DOE must subject the CWG report to unbiased, robust, and transparent peer review under the Information Quality Act and other federal requirements. Accordingly, it will require very substantial revision before it can be relied upon by any federal agency or other entity.

Sincerely,



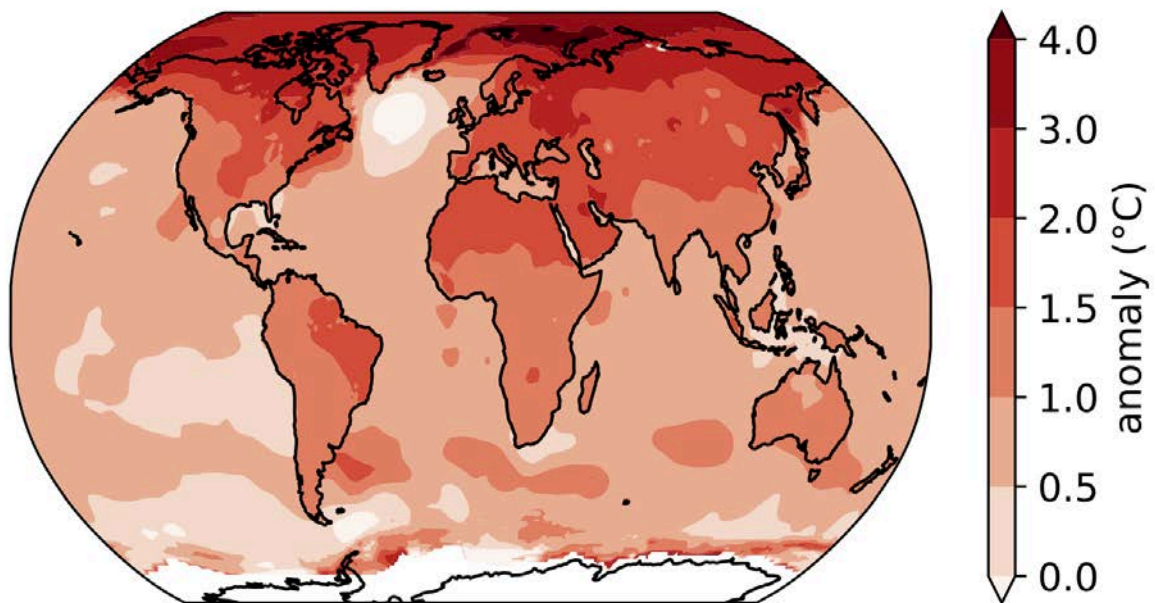
Andrew E. Dessler, Ph.D.
Co-Editor, *Climate Experts' Review of the DOE Climate Working Group Report*



Robert E. Kopp, Ph.D.
Co-Editor, *Climate Experts' Review of the DOE Climate Working Group Report*

Climate Experts' Review of the DOE Climate Working Group Report

Comment submitted to the U.S. Department of Energy, docket number DOE-HQ-2025-0207, in response to their report "A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate"



This report may be cited as:

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Individual sections may be referenced as, for example:

D.S. Nolan, D. Chavas, K. Emanuel, A.J. Garner. (2025). Comment on the DOE CWG report, Section 6.2: Hurricanes and Tropical Cyclones. In A.E. Dessler and R.E. Kopp (Ed.), *Climate Experts' Review of the DOE Climate Working Group Report* (pp. 162-173). DOI: to be assigned, URL to be assigned

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Climate Experts' Review of the DOE Climate Working Group Report

Summary for Policy Makers

Andrew E. Dessler, Texas A&M University

Robert E. Kopp, Rutgers University

The basic science of Earth's climate has been well established through two centuries of research. Over the 16 years since the Environmental Protection Agency's 2009 Endangerment Finding, the evidence for human-caused climate change and the dangers it poses to public health and welfare has continued to grow stronger. The report authored by the five members of the Department of Energy (DOE) Climate Working Group (CWG) and released by DOE on July 29, 2025, fails to adequately represent this reality.

This document is an expert review of the DOE CWG report. It represents the collective, self-organized efforts of more than 85 climate experts over the report's short, month-long comment period. As our review details, the CWG report exhibits pervasive problems with misrepresentation and selective citation of the scientific literature, cherry-picking of data, and faulty or absent statistics.

The DOE CWG report does not meet standards of quality, utility, objectivity and integrity appropriate for use in supporting policy making. In assessing the science of climate change, the U.S. government should follow standards appropriate for a Highly Influential Scientific Assessment, including an unbiased, robust, and transparent peer review process. Rigorously reviewed assessments, like the Intergovernmental Panel on Climate Change and National Climate Assessment reports, provide much more accurate representations of the scientific understanding of climate change.

The basic science of Earth's climate has been well-established through two centuries of research. Over the 16 years since the Environmental Protection Agency (EPA)'s 2009 Endangerment Finding, the evidence for human-caused climate change and the dangers it poses to public health and welfare has continued to grow stronger.

Recent assessments, such as the Intergovernmental Panel on Climate Change (IPCC)'s 2021 Sixth Assessment Report (AR6), confirm that the evidence shows that human influence is warming the atmosphere, ocean, and land in a way that is unprecedented for many centuries to millennia. The evidence that human-caused climate change is changing heat waves, heavy

rainfall events, droughts, hurricanes, and wildfires has grown. Across the coastal U.S., outside of parts of Alaska, rising sea levels are incontrovertibly causing an increase in coastal flooding.

The frequency, intensity, and duration of heat waves is increasing globally as a result of long-term, human-caused warming driven by greenhouse gas emissions.¹ **[Comment (Cmt.) 20, 37]** The magnitude and intensity of extreme precipitation has very likely increased since the 1950s in North America as a whole, and particularly in eastern North America.² **[Cmt. 21]** Climate change has intensified hydrological, ecological, and agricultural drought in the western U.S. and other regions around the world over the past few decades.³ **[Cmt. 24]**

Although no trends in the number of hurricanes making landfall in the U.S. have been detected (and none were expected), hurricanes are becoming more hazardous. They are reaching higher intensity and intensifying more quickly. Higher sea levels are making their coastal flooding more extensive and damaging, and atmospheric warming is leading them to produce more rainfall, which is increasing their inland impacts.⁴ **[Cmt. 18]**

Climate change has led to increased fire weather, longer fire seasons, and drier fuels. As a consequence, the likelihood and intensity of the most extreme wildfires has increased in North America, with major effects in the western U.S. These extreme fires have generated substantial ecological, economic, health, and livelihood impacts across the U.S. The consequences extend far beyond fire-prone regions due to smoke transport across continental distances, exposing populations nationwide to serious health risks.⁵ **[Cmts. 25, 26]**

Sea-level rise is increasing risk to coastal communities. The rate of global-mean sea-level rise has more than doubled over the last 30 years, from about 0.08 inches/year in 1992 to 0.18 inches/year in 2024, and statistical analysis also reveals sea-level acceleration at many U.S. tide gauges and in contiguous U.S. tide gauges in aggregate. Along parts of the U.S. Atlantic and Gulf coasts, the number of days of coastal flooding per year have increased more than ten-fold since the 1970s as a result of sea-level rise, and relative sea-level rise is projected to increase high-tide flooding by 5-10x on average across the country's coast by 2050.⁶ **[Cmt. 27]**

¹ The DOE CWG Report claims otherwise based on a fallacious interpretation of Dust Bowl conditions in the U.S. in the 1930s; see discussion below.

² The DOE CWG Draft Report claims otherwise based on limited sampling of the available data and precipitation extreme metrics.

³ The DOE CWG Report focuses exclusively on meteorological droughts, which are evaluated based on low rainfall alone. Other definitions of drought are more relevant to impacts on public welfare. Agricultural and ecological drought are defined as water insufficient to meet agricultural and ecological needs, and factor into account phenomena like soil moisture and water balance (evaporation minus precipitation). Hydrological droughts are assessed based on low surface water flow and changes in runoff.

⁴ The DOE CWG Report focuses on the (unsurprising) absence of a trend in landfalling hurricane frequency, while ignoring the evidence that hurricanes are becoming more hazardous.

⁵ Illustrating the single-cause fallacy, the DOE CWG ignores the evidence for changes in fire weather and focuses exclusively on the role of fire management practices.

⁶ The DOE CWG Report claims there is "no obvious acceleration in sea-level rise". It does not provide any statistical analysis to support this claim, nor does it discuss the extensive scientific literature demonstrating acceleration. The CWG Report does not discuss the present or future impacts of sea-level rise.

Economists have concluded that these and other effects of climate change will likely have significant negative impacts on the U.S. and global economy. Every additional ton of greenhouse gas emitted into the atmosphere increases global average temperature, and every additional amount of global warming escalates the danger to public welfare.⁷ [Cmt. 43]

The report authored by the five members of the Department of Energy (DOE) Climate Working Group (CWG) and released by DOE on July 29, 2025, fails to adequately represent the current scientific understanding of climate change.

In contrast to the requirements for a committee established under the Federal Advisory Committee Act (FACA), no attempt appears to have been made to balance the points of view represented on the CWG; rather, this group appears to have been personally recruited by the Secretary of Energy to advance a particular viewpoint favored by DOE leadership.⁸ The CWG members have, to their credit, previously published some of the ideas reflected in the CWG report in the peer-reviewed literature. The scientific community has previously examined them and delivered a collective, resounding rejection.⁹

Beyond the unbalanced membership of the CWG, the process that led to the CWG report does not include other guardrails to minimize bias in the report. For example, in contrast to the requirements for a FACA committee, the CWG's deliberations have been conducted in secret and without public record or notice. This also stands in contrast to the aims proclaimed by Executive Order 14303 ("Restoring Gold Standard Science"), which calls for science to be conducted in a manner that is transparent, without conflicts of interest, and subject to unbiased peer review.

It is also worth noting that an assessment of this type would normally have hundreds of authors, and would be written over the course of multiple years, with multiple rounds of internal and external review. A large author team allows each section to be written by experts on that exact topic. The DOE CWG report, due to its very small writing team, covers areas in which the authors are not experts and has led to many errors in the report caused by a lack of familiarity with the science.¹⁰

⁷ As discussed below, the DOE CWG Report focuses on the small number of studies suggesting climate change is less damaging than most analyses suggest is most likely, while ignoring the larger number of studies suggesting climate change is more damaging than central estimates.

⁸ <https://www.cnn.com/2025/08/07/climate/wright-national-climate-assessments-updating>

⁹ The Report relies unusually heavily on citations to the authors' own work. Overall, nearly 11% of all citations in the report are to the work of one of the report authors. In chapters 3 and 5, more than a quarter of citations are self-citations. This compares to an average of 2.4% and a chapter maximum of 5.1% in the IPCC AR6 Working Group 1 report. [Cmt. 48]

¹⁰ For example, the authors exhibit basic confusion about the concepts of Climate Impact Drivers and time of emergence [Cmt. 36]. They do not understand how the climate component of integrated assessment models are calibrated [Cmt. 43]. They do not correctly define relative sea-level change, and highlight as a major conclusion the important role of vertical land motion in relative sea-level change – something that has been understood since the nineteenth century [Cmt. 27].

It is important to note the severe time constraints imposed on reviewing this document. The 30-day review period was inadequate for conducting a thorough and systematic analysis of this report.¹¹ Given that, we have undoubtedly failed to identify numerous additional errors, misrepresentations, and critical omissions throughout the text, and we have made errors of our own. The deficiencies highlighted in our comments should therefore be viewed as the tip of the iceberg — the document's true problems almost certainly extend far beyond what we were able to catalog in the limited time available.

This document is an expert review of the CWG report. It represents the collective, self-organized effort of more than 85 climate experts over the short, month-long comment period invited by Federal Register notice 90 FR 36150.

We are submitting our expert review in response to this Federal Register notice, but do so in full recognition that the notice provides no details on the review process.

The DOE CWG Report clearly meets the definition of a Highly Influential Scientific Assessment (HISA) under the Office of Management and Budget (OMB)'s Final Information Quality Bulletin for Peer Review (70 FR 2664). As such, OMB and EPA guidance require an unbiased peer review comparable in rigor to that conducted by the National Academies, as well as opportunities for public participation in report review and full documentation of responses to peer review comments. **[Cmt. 47]**

The obscure nature of the CWG review process stands in contrast to the process employed by National Climate Assessments (NCAs), which comply with the requirements for HISAs. The NCA reports undergo multiple stages of expert and public review, including peer review by the National Academies of Sciences, Engineering, and Medicine. The NCA's review editors — a group of experts independent of the authors — ensure that the report authors seriously consider and provide a public, written response to every substantive public and National Academies comment.¹² We do not know whether to expect from the CWG a similarly transparent, thorough, and independently overseen response to comments like ours.

As detailed in the over 400 pages of our expert review, the DOE CWG Report exhibits pervasive problems with misrepresentation and selective citation of the scientific literature, cherry-picking of data, and faulty or absent statistics.

Below, we discuss some high-level examples.¹³

¹¹ By comparison, the Third Order Draft of the Fifth NCA allowed for a 12-week comment period.

¹² While GlobalChange.gov, the Internet home of the US Global Change Research Program for more than a quarter-century, was shut down on June 30, 2025, the annotated responses to comments on the 2023 Fifth National Climate Assessment can be accessed through the Internet Archive at <https://web.archive.org/web/20250630050603/https://nca2023.globalchange.gov/downloads/>.

¹³ For an overview of rhetorical strategies and reasoning fallacies that often appear in climate misinformation, see Cook, J. (2020). Deconstructing climate science denial. In D. C. Holmes & L. M. Richardson (Eds.), *Edward Elgar Research Handbook on Communicating Climate Change* (pp. 62–78). Edward Elgar Publishing. <https://doi.org/10.4337/9781789900408.00014>

Climate projections are driven by scenarios of future emissions of greenhouse gases and other climate forcers. The DOE CWG Report broadly claims that “scenarios widely-used in the impacts literature have overstated observed and likely future emission trends” (p. ix). This ambiguous language misrepresents the fact that climate scenarios are deliberately constructed to span a broad range of possible futures, from very low emissions to very high emissions. Current emissions of carbon dioxide from fossil fuels and land use are tracking near the middle of the scenario range used in AR6. Under AR6’s Intermediate emissions scenario (SSP2-4.5), which assumes declining global CO₂ emissions in the second half of the century, late-century warming will very likely be 2.1-3.5°C above late nineteenth-century levels (about 1.5-2.9°C warmer than the 1990 baseline used in the EPA’s Endangerment Finding). **[Cmt. 4, 6]**

The DOE CWG Report argues that climate models do not accurately describe recent climate trends. Toward that end, the DOE CWG cherry-picks evidence that support a low equilibrium climate sensitivity (ECS)¹⁴ while ignoring or downplaying an overwhelming body of contradictory evidence that collectively led the IPCC to conclude that ECS is likely between 2.5°C and 4.0°C for a doubling of carbon dioxide concentrations. It also focuses on the highly uncertain, multi-century metric of ECS over less uncertain, more policy-relevant metrics, like those characterizing the nearer-term response of the climate to carbon dioxide emissions. **[Cmt. 9, 10]**

Indeed, in a separate part of its report, the DOE CWG Report accurately highlights the recent rapid increase in global mean surface temperature, with temperature in 2023 surpassing the previous record by nearly 0.2°C, and elevated temperatures persisting into 2025. As the DOE CWG Report notes, this is a topic of active scientific research, and might be tied to a decrease in the planet’s albedo (reflectivity). One possible cause of this decrease is a potential strong positive cloud feedback; if true, this would argue for a higher ECS. This discussion is, however, ignored in the report’s argument that climate models are too sensitive to greenhouse gas-induced warming. **[Cmt. 9, 35]**

The DOE CWG Report highlights the Dust Bowl period of the 1930s as a time of unusually hot temperatures in the United States, a period that in parts of the contiguous United States still dominates high temperature records. This is another example of cherry picking, as well as an example of the single cause fallacy (specifically, the idea that, because climate has varied naturally in the past, current changes must also be natural). However, over such a small area, natural variability plays a very large but temporary role. The Dust Bowl was indeed an exceptional event, and the decadal climate conditions that drove the Dust Bowl are not occurring today. Thus, the comparison between the 1930s and today does not tell us about the impact of anthropogenic climate change on today’s extreme temperatures. The fact that high-temperature records are being reliably broken more frequently than low-temperature records – both globally and in the U.S. – is a clear indicator that humans are making extreme high temperatures more extreme. **[Cmt. 19, 20]**

¹⁴ ECS measures the long-term (millennial-scale) response of global mean temperature to a fixed forcing, conventionally taken as an instantaneous doubling of carbon dioxide concentrations from their preindustrial levels

To argue that climate models overestimate warming, the DOE CWG Report, in another example of cherry-picking, highlights the U.S. Corn Belt, an area which makes up less than 1% of the area of the planet. The Corn Belt is the most agriculturally productive region on the planet – an area where land-use changes and natural variability over the last few decades have largely offset greenhouse gas warming. To the extent that models have problems in this very small region, it is connected to how well the models are handling the specific land-use changes occurring only in this region, not how well they represent global warming. In fact, in areas across the Northern Hemisphere, climate models are equally likely to overestimate or underestimate warming – exactly as expected for models that get the warming right. **[Cmt. 17]**

While in some cases, climate change can yield local benefits, on net its effects are harmful to welfare and economic output in the United States. **[Cmt. 38-43, 45]**

Although increasing carbon dioxide concentrations in isolation can increase crop yields, the DOE CWG report's focus on carbon fertilization is an oversimplification. In the real world, crops must simultaneously contend with the climatic effects of increasing greenhouse gases, including hotter temperatures and enhanced evaporation. The evidence suggests that CO₂-induced climate change, including rising temperatures, shifting weather patterns, and altered precipitation, will outweigh the benefits of CO₂ fertilization, leading to net yield declines across major agricultural regions in the U.S. and globally compared to what would happen without rising CO₂ concentrations. **[Cmt. 38]**

Although the DOE CWG Report notes that cold-related deaths in the United States are higher than heat-related deaths, their discussion overlooks the complexity of how climate change will reshape mortality patterns. While global warming may initially reduce deaths in some regions and increase them in others, heat-related mortality will increasingly dominate as temperatures continue to rise. The report also makes unrealistic assumptions about adaptation through air conditioning, failing to account for economic barriers that prevent access. Even in wealthy countries like the U.S., the poorest communities struggle to afford air conditioning, and this challenge is far more severe in developing nations. The DOE CWG report also ignored the fact that climate change has health impacts other than temperature-related mortality. These include a variety of pathways other than temperature, such as vector-borne diseases (like malaria and Lyme disease), food security and malnutrition, and air quality. **[Cmt. 41, 42]**

Human well-being is intertwined with the stability of natural systems: from safe food and clean water to disease regulation, mental health, and cultural identity. The DOE CWG Report omits discussion of the disruptive effects of climate change on wildlife and biodiversity, which are altering predator-prey relationships, increasing disease risks, and destabilizing ecosystems that underpin human well-being. The resulting economic impacts include reduced pollination and fisheries yields, damage to aquaculture, declines in ecotourism, costs from invasive species and harmful algal blooms, and cultural losses tied to species extinctions. By neglecting biodiversity impacts, the DOE CWG Report misses a key pathway by which greenhouse gas emissions endanger human health and prosperity. **[Cmt. 45]**

Adaptation is essential to manage climate risk, but it cannot eliminate it. For example, adaptation can reduce, but not eliminate, damages associated with future sea-level rise. Yet the United States is not optimally adapted even to current coastal hazards. Economically efficient adaptation will require substantial investments by individuals, industries, and all levels of government well in advance, and failure to make such investments will decrease economic stability. Furthermore, many low-lying regions will reach adaptation limits over the course of this century. However, the discussion of adaptation in the DOE CWG Report is very limited, and does not consider the costs of and barriers to either private or public adaptation, about which there is a significant literature. **[Cmt. 27]**

The climate can only be stabilized through the cumulative effect of many mitigation actions, and each marginal effort brings benefits for human welfare. In its discussion of the economic costs of climate change – and thus of the economic benefits of reducing greenhouse gas emissions – the DOE CWG Report looks at uncertainty about climate change and its impacts through rose-tinted glasses. It focuses not even on the most common estimates of possible outcomes, but on a cherry-picked set of outcomes where everything turns out better than most analysts expect, let alone fear. A long history of work on risk management points to the importance of considering the full distribution of outcomes, including low- or unknown-likelihood outcomes associated with high-impact risks. The DOE CWG's general approach would also argue against the purchase of insurance, the maintenance of a standing army in peacetime, and many other regularly accepted precautionary measures. **[Cmt. 43, 44]**

In short, the DOE CWG Report does not meet standards of quality, utility, objectivity and integrity appropriate for use in supporting policy making. In assessing the science of climate change, the U.S. government should follow standards appropriate for a Highly Influential Scientific Assessment, including an unbiased, robust, and transparent peer review process. Rigorously reviewed assessments, like the Intergovernmental Panel on Climate Change and National Climate Assessment reports, provide much more accurate representations of the scientific understanding of climate change.

About the writing team

This report arose organically when Dr. Andrew Dessler asked on Bluesky whether anyone was coordinating a response to the DOE CWG Draft Report. ¹⁵Following his inquiry, multiple people encouraged him to take on the coordination role, which he ultimately agreed to do. He then put out a call for volunteers on social media. Many signed up and, as word spread, more scientists contacted him and volunteered to write a section. As the workload expanded, Dr. Robert Kopp volunteered to be co-editor of the effort.

In the end, more than 85 scientists contributed. Authors are mostly from the U.S., but with important contributions from Europe, Asia, Australia, and Canada. The age distribution was evenly split between early career, mid career, and senior. About 80% of the authors work at universities, with the rest at a variety of other institutions.

This report is the result.

Each section was authored by a particular writing team and responsibility for the contents of that section rests solely with them. Affiliations listed for any authors are included for identification purposes only. The opinions, findings, conclusions, and recommendations expressed are those of the authors and not their institutions. Some authors wished to remain anonymous, and they are not listed.

We would also like to acknowledge the editing team that took the disparate sections and, despite the extremely short time frame, put this document together: Lauren Cagle, Chris Colose, Jillian Gregg, Genevieve Guenther, Marc Jones, William Ripple, and Emily Williams.

¹⁵ <https://bsky.app/profile/andrewdessler.com/post/3lv4wamrpes2e>

Response to Chapter 2, Section 2.1: CO₂ as a contributor to global greening

David J Beerling, Ph.D.; Benjamin Brown-Steiner, Ph.D.; Anna B. Harper, PhD.; Rosie A. Fisher, Ph.D.; Rebecca B. Neumann, Ph.D.; Ben Poulter, Ph.D.; Scott R. Saleska, PhD.; Abigail L.S. Swann, PhD.; Emily Williams, Ph.D.

Overview of Comments on this Section

Pages 3-6

Comment Type: Technical

Section 2.1 focuses on the role of CO₂ in causing “greening,” or the enhancement of photosynthesis. The section overlooks the fact that it is the net carbon balance of terrestrial ecosystems that matter for the climate system, not just the rate of photosynthesis. The effect of CO₂-driven changes to climate, including increased temperature and changes in water stress, on terrestrial net carbon balance are not discussed in any sections of the report, leading to the false impression that increased CO₂ levels *only* result in an improvement in plant productivity. The net uptake of carbon by terrestrial ecosystems is expected to saturate as climatic changes continue. The uptake will also possibly reverse. Section 2.1 of the DOE Report implies that the IPCC is masking or hiding the well-established phenomenon of CO₂ fertilization of plant growth, when, in reality, it informs the IPCC assessments as a foundational principle of the models used to simulate the terrestrial carbon cycle. CO₂ fertilization, moreover, remains only one of many competing factors that drive plant productivity, ecosystem health and net terrestrial carbon balance.

ACTION: Report authors need to include discussion of all the CO₂-driven climate changes that affect ecosystems – beyond the ‘greening’ effect – and include discussion of all the components of the terrestrial carbon budget, not just plant photosynthesis.

Below we provide specific comments to statements made throughout Section 2.1

Chapter Summary

Page 3

Comment Type: Technical

DOE CWG STATEMENT: *“The growing CO₂ concentration in the atmosphere has the important positive effect of promoting plant growth by enhancing photosynthesis and improving water use efficiency. That is evident in the “global greening” phenomenon discussed below, as well as in the improving agricultural yields discussed in Chapter 10. Here we focus just on CO₂ fertilization; research on combined effects due to temperature and precipitation changes are discussed in Chapter 10.”*

COMMENT: The impact of elevated CO₂ on agriculture is discussed in Chapter 9 of the DOE CWG Report, not Chapter 10. This is a typo in the report that needs to be fixed. We will refer to the correct chapter number (i.e., Chapter 9) in our comment. As highlighted in the detailed responses to Chapter 9, it is a misrepresentation of the science to state that growing CO₂ concentrations will improve agricultural yields. In addition, Chapter 9 includes minimal discussion of “research on combined effects due to temperature and precipitation changes,” as highlighted in the comments to Chapter 9. The report authors need to add discussion of these combined effects to Chapter 9 and include the studies cited in the comments that were made to Chapter 9.

The section that focuses on “CO₂ as a contributor to global greening” is inaccurate, because it looks solely at the effects of CO₂ (via CO₂ fertilization) without looking at the other effects of CO₂ (on increased temperature, etc.; see Grossiord et al. 2020). Ignoring the combined effects that rising CO₂ levels will have on the Earth system (e.g., warmer temperatures and altered precipitation patterns) means the report does not provide a robust assessment of the true impact that rising CO₂ levels will have on plant growth and ecosystems.

In addition, not all plants respond similarly to enhanced CO₂. The concept of global greening does not account for changes to species composition in ecosystems, which could have important implications for biodiversity and ecosystem health (Bond & Midgley, 2012; O. Phillips et al., 2002). For example, shrub growth into savannas is linked to higher atmospheric CO₂ levels (Manea & Leishman, 2019; Nackley et al., 2018). Uniformly declaring the effects of enhanced CO₂ as ‘positive’ is misleading.

ACTION: The introduction to Section 2.1.1. should mention other effects of higher CO₂ levels in the atmosphere (rising temperatures, altered precipitation patterns, increased aridity, greater risk for fires, pests, and disease). A more thorough discussion of the many impacts of these factors on plant growth, agriculture, and biodiversity should be included within the report. Critical references that should be included in this report can be found in our comment below to section 2.1.1, last paragraph page 5. The authors should caveat the term ‘positive’ to more accurately reflect the balance of changes that occur with higher levels of CO₂. Remove “as well as in the improving agricultural yields discussed in Chapter 10.”

2.1.1. Measurement of global greening

Page 3-4

Comment Type: Technical

SUMMARY OF COMMENTS ON THIS SECTION: Section 2.1.1 deals with global greening, but we found statements that mask the complexities of patterns and trends noted by greening studies. Global greening has occurred, but the drivers underlying the trend are complex and can be affected by factors other than CO₂. We suggest multiple changes so the report can more accurately describe the varying effects of CO₂ on global patterns detailed below.

Page 3

Comment Type: Technical

DOE CWG STATEMENT (first paragraph of section 2.1.1, page 3): *“Greening” refers to an increase in the fraction of the Earth’s surface covered by plants. It can be quantified by the “Leaf Area Index” (LAI) measured by satellite.”*

COMMENT: The definition of ‘greening’ used in the DOE report is overly simplistic, and it is incorrect to say that it is quantified by changes to LAI only. Greening refers to changes in leaf area index (LAI) or the fraction of photosynthetically absorbed radiation (FPAR) over time within a defined area (Piao et al., 2020). The DOE report uses a definition that implies ‘greening’ is an expansion of vegetation into areas that were previously non-vegetated. This implication is false, which is important because the DOE report thus incorrectly interprets the literature on ‘greening’ throughout this section.

ACTION: The report authors need to correct the definition of greening to include changes in vegetation indices based on FPAR and the subsequent interpretation of the implications of greening.

Page 3

Comment Type: Technical

DOE CWG STATEMENT (first paragraph of section 2.1.1, page 3): *“Zhu et al. (2016) was one of the first studies to report that global greening was detectable using satellite sensors. From 1982 to 2011 they detected greening over 25-50 percent of the Earth versus “browning” over only four percent and attributed 70 percent of the greening to rising CO₂ levels (see Figure 2.1).”*

COMMENT: The Zhu et al. (2016) paper is among many prominent papers cited by the IPCC that document the long literature on global greening and browning (c.f. Myneni et al. 1997; Nemani et al 2003; Zhao and Running 2010). The more recent literature highlights slowdowns in greening attributed to the changing climate (Yuan et al 2019) and provides a richer accounting of the effects on ‘greening’ biome differences and land use.

Cortés et al (2021) make improvements on the statistical approach for identifying regions of greening, and find a much reduced area of greening that covers only 15.3% of the land surface.

Yuan et al. (2019) find that the ‘global greening’ trend reversed across most of the world and, in the US, was concurrent with a sharp increase in VPD observed starting in the late 1990s. In other words, they find that while the CO₂ fertilization effect dominated from 80s-90s, after the late 1990s, VPD partially (but not fully) counteracts it. Winkler et al. (2021) find a slowing down of greening and strengthening of browning trends, particularly in the last 2 decades, and they also find that most models substantially underestimate the emerging vegetation browning, especially in the tropical rainforests. Piao et al. (2020) report that most of the greening is taking place in boreal ecosystems, with the tropics greening less or browning, due to negative effects of climate change. Along these lines, Figure 2.1 is reproduced from Zhu et al. (2016) but fails to acknowledge that stippling on the map indicates statistically significant trends, and because only some regions are stippled this shows that trends in many regions are not robust. Furthermore, the location of greening has important implications for how any increases in photosynthesis translate into climate- relevant ecosystem properties such as net land carbon sinks, as well as for the impact on climate of changes in leaf area, given that a higher expanded leaf area index is typically associated with warming in boreal regions (Y. Li et al., 2023; W. Zhang et al., 2018).

ACTION: The report authors need to update the estimated regions of greening and browning to be consistent with more recent publications (i.e. Winkler et al., 2021, Cortés et al., 2021, Piao et al., 2020) and to discuss which regions are experiencing greening or browning with statistical significance. Figure 2.1 caption needs to add that only stippled points were found to have statistically significant trends. Further the report needs to add discussion of the implications of greening trends in specific regions that may be the result of anthropogenic driven land cover change, i.e. agricultural land management or afforestation (Piao et al. 2020).

Page 3

Comment Type: Technical

DOE CWG STATEMENT (second paragraph of section 2.1.1, page 3): “Zeng et al. (2017) confirmed the pattern of greening, noting that over thirty years it had added 8 percent to global leaf area and that greening was mitigating warming”

COMMENT: The statement oversimplifies the global impact versus regional impacts of greening. The statement, based on a model simulation with a single version of a single Earth System Model, implies that the effect of greening (i.e. darkening of the surface) is to cause global cooling, but any potential cooling is limited to specific regions where plants cool through large water fluxes, primarily the tropics (Bonan 2008). Importantly, in the boreal region where most observed greening has occurred, greening can contribute to enhanced warming due to the lower albedo of boreal forests compared to tundra or snow (Betts, 2000; Y. Li et al., 2023). Cooling of tropical and warming of boreal systems has been confirmed using satellite observations by (Forzieri et al., 2017).

ACTION: The authors need to add additional discussion about the expected climate impacts of leaf area increase in different regions, in particular that darker surfaces in high latitudes cause additional warming (G. B. Bonan, 2008).

Comment Type: Technical

DOE CWG STATEMENT (second paragraph of section 2.1.1, page 3): *“Piao et al. (2020) noted that greening was even observable in the Arctic.”*

COMMENT: This statement implies that the Arctic greening signal was caused by elevated CO₂, however that is not the scientific consensus. Piao et al. (2020) attribute the greening trend in the Arctic predominantly to growing season length driven by warmer temperatures (see also Y. Zhang et al., 2022). Piao et al. (2020) also note that this positive impact of increasing temperatures appears to have weakened over the past four decades, “suggesting a possible saturation of future greening in response to warmer temperature” (see also comment on greenness trends related to Section 2.1.1, first sentence of Page 4). It is also important to put Arctic greening more broadly into the context of the carbon cycle and other impacts. While above-ground plants may have displayed more leaf area over the past decades, rising temperatures also thaw permafrost and drive accelerated decomposition in highly carbon rich soils (Turetsky et al., 2020), a process which is expected to accelerate as climate continues to warm (Miner et al., 2022). Thus even with Arctic greening, high latitude terrestrial systems may become net carbon sources to the atmosphere, causing an amplifying feedback (Braghiere et al., 2023). Other risks to the Arctic linked to higher CO₂ levels and rising temperatures are not mentioned in this report (Virkkala et al., 2025). The Arctic is warming at a rate of 2 to 3 times the global average, leading to thawing of permanently frozen soils (permafrost), with downstream impacts including loss of structural support for buildings and subsidence, threatening communities, roads, runways, and other assets across Alaska (Manos et al., 2025; University of Alaska Fairbanks Institute of Northern Engineering US Army Corps of Engineers Alaska District & Laboratory, 2019).

ACTION: The report authors need to:

- add additional discussion of the role of temperature and other global change factors on observed greening trends in the Arctic
- add discussion that beneficial effects of global change seen in some high latitude regions are likely to saturate and possibly even reverse
- add discussion of how Arctic greening is counteracted by accelerated decomposition, weakening the carbon sink and likely leading to a net carbon source inclusive of the references above.
- The potentially positive effects of Arctic greening should be counter-balanced by negative effects of Arctic warming including melting permafrost and threats to infrastructure.

DOE CWG STATEMENT (last paragraph of section 2.1.1, page 3): *“While plant models predict increased photosynthesis in response to rising CO₂, Haverd et al. (2020) reported a CO₂ fertilization rate much larger than model predictions. That is, CO₂ fertilization had driven an increase in observed global photosynthesis by 30 percent since 1900, versus 17 percent predicted by plant models. If true it would indicate that global models of the socioeconomic impacts of rising CO₂ have understated the benefits to crops and agriculture.”*

COMMENT: The statement is incorrect for multiple reasons. First, the Haverd et al., (2020) study does not focus on agriculture, but on the net carbon exchange between the global biosphere and the atmosphere. Thus it does not support any statements about the response of crops or agriculture specifically. Second, Haverd et al., (2020) also uses a prediction from the CABLE land surface model to attribute how much of the historical change in gross primary production was likely caused by increasing CO₂. Their predictions are thus subject to similar uncertainties to other models used for this purpose. It is therefore incorrect to say that the estimate is “larger than model predictions” because the estimate from Haverd et al. (2020) is also a model prediction. Further, while the Haverd et al. model prediction is higher than the mean, it is still within the range of GPP responses to historical CO₂ change predicted by the ensemble of carbon cycle models to which it is compared. So it does not actually represent a deviation beyond the range represented by existing approaches. It is also relevant that much of the global increase in GPP estimated using the model of Haverd et al., (2020) comes from tropical forests, but the long-term ecosystem scale CO₂ responses of these forests remains unknown, in the ongoing absence of the CO₂ manipulation experiments which would be necessary to determine this (Amigo, 2020). Many studies have predicted that the low phosphorus concentrations of soils in the Amazon in particular (Quesada et al., 2010) are likely to limit this response (Cunha et al., 2022; Fleischer et al., 2019). More recent literature that the DOE CWG cites (Keenan et al., 2023) argues for a lower CO₂ fertilization response of photosynthesis. Finally, these estimates of high rates of CO₂ fertilization and greening have not yet been reconciled with recently available remotely sensed estimates of trends in above ground biomass estimated from tree height which show little increase over the past two decades (L. Xu et al., 2021).

With respect to crop model performance, many studies have concluded that crop models underestimate the negative impacts of climate extremes on crop production (Barriopedro et al., 2023; Heinicke et al., 2022; Kornhuber et al., 2023; C. Zhao et al., 2017). Accordingly, focusing on a single outlying model result gives a misleading picture of their uncertainties.

ACTION: The report authors need to remove the incorrect statement that “Haverd et. al (2020) reported a CO₂ fertilization rate much larger than model predictions”. If they choose to discuss Haverd et al. (2020) they should include the caveats outlined above. The final sentence “if true...” should be removed given that it is unreasonable to extrapolate from the results of a single study, especially given that the results don’t fall outside of the range of prior estimates.

Page 4

Comment Type: Technical

DOE CWG STATEMENT (Section 2.1.1, first sentence on Page 4): *“Piao et al. (2020) and Chen et al. (2024) report that the greening trend continues with no evidence of slowdown, and CO₂ fertilization remains the dominant driver”*

COMMENT: This statement is incorrect. Piao et al. (2020) conclude that although “vegetation greenness is increasing at the global scale, the changes vary considerably between regions and seasons.” This is not the same as saying there is no evidence of a slowdown. And in fact, Chen et al. (2024) found that a trend of increasing drought stress slowed the rate of greening from 2001 to 2020. Also, other studies — already mentioned in our comment on the first paragraph of section 2.1.1, page 3 — find a slowing down or reversing of the greening trend in many regions (Winkler et al., 2021; Yuan et al., 2019).

Moreover, the possible drivers of greening are the CO₂ fertilization effect, warming temperatures, land use change, and nitrogen deposition, and the dominant driver depends on the region. While Piao et al. (2020) attributed global trends in LAI to CO₂, warming from climate change has a positive effect in northern high latitudes (>50N) but a negative effect in the southern hemisphere extratropics.

ACTION: The authors should replace this statement with a discussion that more accurately reflects the established literature and current state of knowledge on trends and drivers of greening, including references mentioned here and in our previous comment.

2.1.2. Photosynthesis and CO₂ levels

Page 4-5

Comment Type: Technical

SUMMARY OF COMMENTS IN THIS SECTION: Section 2.1.2 suggests that plants (especially C3 plants) will benefit from additional CO₂ in the atmosphere. We agree that leaf-level photosynthesis increases under ideal conditions under elevated CO₂, but this section (like the entire report) neglects a large body of evidence that warming, drought, and nutrient limitations ultimately lead to reductions in photosynthesis in experimental studies. These negative effects have been observed in several regions across the globe.

ACTION: This section needs to be revised to include the rich body of literature that has investigated the impact of CO₂-driven climate change on ecosystems.

Page 4

Comment Type: Technical

DOE CWG STATEMENT: *“Over geological time the Earth’s atmospheric CO₂ levels were usually many times higher than they are today. About 400 million years ago CO₂ levels were an*

estimated 2,000-4,000 ppm and were at or above 1,000 ppm for much of the interval from 200 to 50 million years ago (Berner 2006, Judd et al. 2024). Over the past 35 million years the level of atmospheric CO₂ has been steadily declining, falling to as low as 170 ppm during glaciations (Gerhart and Ward 2010). While the modern rate of change in CO₂ may be high compared to prior intervals, the geological evidence is that plants and animals evolved under much higher CO₂ levels than at present.”

COMMENT: This section is misleading and not relevant for evaluating if anthropogenic climate change poses risks to plants, animals, and human beings. For one, many plants (C4 and CAM) and extant terrestrial mammals, including modern humans, evolved under CO₂ concentrations that did not exceed ~550ppm (CENCO₂PIP, 2023). Further, this statement diminishes the relevance of the rate of change of CO₂ and associated warming which is unprecedented in the fossil record. The closest comparable situation in the fossil record is the Paleocene-Eocene Thermal Maximum (PETM) when there was a fast injection of CO₂ into the atmosphere with rapidly warming climates (Tierney et al., 2022). This rapid rise of CO₂ coincides with mass extinctions in the ocean and reshuffling/migrations of organisms on land (Huurdeeman et al., 2020; Zachos et al., 2001).

ACTION: The report needs to add a discussion of the relevance of the rate of change we are experiencing in CO₂ levels and CO₂-induced warming to ecosystems and organisms, or remove the statement entirely.

Page 4

Comment Type: Technical

DOE CWG STATEMENT (section 2.1.2, last paragraph on page 4): *‘Had atmospheric CO₂ levels continued declining, plant growth would have declined and eventually ceased’*

RESPONSE: This statement is a) uncited b) not supported by theory, as continued drawdown of CO₂ depends on the continued growth of plants, c) inapplicable to the Earth system as we know it because over the past 485-million years, atmospheric CO₂ concentrations never dropped below ~180 ppm (Judd et al., 2024), and d) irrelevant to our modern-day situation where CO₂ is 430ppm.

ACTION: The authors need to remove this statement from the report.

Page 4

Comment Type: Technical

DOE CWG STATEMENT: *“Below 180 ppm, the growth rates of many C3 species are reduced 40-60 percent relative to 350 ppm (Gerhart and Ward 2010) and growth has stopped altogether under experimental conditions of 60—140 ppm CO₂. Some C4 plants are still able to grow at levels even as low as 10 ppm, albeit very slowly (Gerhart and Ward 2010).”*

COMMENT: The CO₂ levels cited in this statement are inapplicable to conditions experienced by the Earth over the past 485-million years. Over the past 485-million years, atmospheric CO₂ concentrations never dropped below ~180 ppm (Judd et al., 2024).

ACTION: The authors need to either remove discussion of plant behavior at CO₂ levels below ~180 ppm or they need to add in the context that these CO₂ levels are below anything experienced by the Earth over the past 485-million years, and thus are of little relevance to our modern day situation.

Page 5

Comment Type: Technical

DOE CWG STATEMENT(section 2.1.1, last paragraph page 5): *“Over the past 60+ years there have been thousands of studies on the response of plants to rising CO₂ levels. The overwhelming theme is that plants, especially C3 plants, benefit from extra CO₂. There are two mechanisms by which CO₂ confers a growth benefit:*

- *Enhanced photosynthesis via the metabolic pathways described above.*
- *Increased water use efficiency. This arises because plants draw in CO₂ by opening the stomata (pores) on the leaf surface. When CO₂ is scarce the stomata must be kept wide open for long periods, allowing water to evaporate. Under enriched CO₂ conditions the stomata remain closed for longer periods, thus helping the plant retain water longer, and so increasing water use efficiency.”*

COMMENT: It is, as the report notes, well known that when plants are exposed to elevated CO₂ under ideal conditions (i.e., adequate water and nutrients and optimal temperatures), leaf-level photosynthesis increases (G. Bonan, 2015; Ficklin & Novick, 2017; Grossiord et al., 2020; Q. Zhang et al., 2019). This well-established understanding is a foundational principle of models used to simulate the terrestrial carbon cycle and land carbon uptake (Farquhar et al., 1980) that inform the IPCC assessments (Arora et al., 2020; Blyth et al., 2021; Canadell et al., 2021). The same is true of enhanced water use efficiency, and the response of stomata to varying CO₂ underlying the modeled leaf stomatal conductance has been present in several generations of Earth system models (Ball et al., 1987; Blyth et al., 2021; LEUNING, 1995).

It is also widely acknowledged that CO₂ is likely driving an increase in land carbon uptake. IPCC AR6 notes that “Increasing global net land CO₂ sink since the 1980s is mainly driven by the fertilization effect from rising atmospheric CO₂ concentrations (Fernández-Martínez et al., 2019; O’Sullivan et al., 2019; Sitch et al., 2015; Tagesson et al., 2020; Walker et al., 2021)(medium confidence)”.

This outcome, as expected from theory, is not surprising. But it is also known that the response of ecosystems to long-term high CO₂ exposure is complex. Free-Air CO₂ Enrichment (FACE) experiments, which are the gold standard in simulating and understanding real-life ecosystem-scale responses to elevated atmospheric CO₂ (Hendrey & Kimball, 1994), have shown that when conditions are not ideal — nutrients are limiting, temperatures are warmer

than optimal, water availability is inadequate — the growth enhancement from elevated CO₂ for both crops and non-agricultural ecosystems often diminishes or disappears (Ainsworth & Long, 2021; DOE, 2020). DOE has carried out ecosystem-scale FACE experiments on a subset of non-agricultural ecosystems. One (ORNL FACE) showed an initial increase in net primary production (NPP) due to elevated CO₂ that then disappeared due to progressive nitrogen limitation, and another (Duke FACE) maintained increased rates of NPP over the duration of the experiment. An arid ecosystem (Nevada Desert FACE) only showed CO₂-induced NPP increases in wet years (DOE, 2020). It is thus anticipated that for some ecosystems, nutrient limitation in particular will constrain the degree to which CO₂ can enhance plant growth (Davies-Barnard et al., 2022; Goll et al., 2012; Terrer et al., 2019; S. Zaehle, 2013; Sonke Zaehle et al., 2011).

Long-term observations of forest dynamics suggest that turnover and mortality rates have increased through time (Büntgen et al., 2019; Marqués et al., 2023; Maschler et al., 2022; O. L. Phillips et al., 2004). Given that these changes have occurred alongside both rising atmospheric CO₂ and climate change, attribution of the causes of changes in mortality rates is challenging (Esquivel-Muelbert et al., 2020; Oliver L. Phillips et al., 2009; Pillet et al., 2018) but growth-driven changes in turnover (the ‘grow-fast, die-young’ hypothesis) are supported by empirical findings (R. J. W. Brienen et al., 2020; Marqués et al., 2023), and align with ecological theory (Bugmann & Bigler, 2011). Given that most Earth System Models omit such trade-offs (Blyth et al., 2021; Fisher & Koven, 2020), projections of CO₂-driven carbon uptake may be overly optimistic (Marqués et al., 2023; Needham et al., 2022; Yao et al., 2024).

Additional consequence of rapid climate change include impacts on the viability of individual species. IPCC AR6-WGII Ch1 notes that *“Climate change increases risks to fundamental aspects of terrestrial and freshwater ecosystems, with the potential for species’ extinctions to reach 60% at 5°C global mean surface air temperature (GSAT) warming (high confidence), biome shifts (changes in the major vegetation form of an ecosystem) on 15% (at 2°C warming) to 35% (at 4°C warming) of global land (medium confidence)”*. Lapola et al. (2025) further argue that direct CO₂ fertilization can be considered a disturbance agent, via impacts on species composition and rainfall (via altered transpiration).

As CO₂ levels rise in the atmosphere, temperatures will concurrently rise. Plants will not experience elevated CO₂ concentrations independently of elevated global temperatures and consequentially altered climate regimes. In cooler regions, rising temperatures can enhance plant growth by extending the growing season, increasing photosynthetic rates, and accelerating nutrient cycling (Arft et al., 1999; Elmendorf et al., 2012; Rustad et al., 2001). However, these benefits are not universal. Way and Oren (2010) noted that while temperate and boreal trees often show increased growth with warming, tropical trees may not exhibit similar responses due to already operating near their thermal optimum. Higher temperatures can also negatively affect plant health by increasing respiratory carbon loss (Lloyd & Taylor, 1994); reducing plant carbohydrate reserves (J. Zhao et al., 2013); reducing photosynthetic efficiency (Didaran et al., 2024); and exacerbating water stress (Farquhar et al., 1980; Wahid et al., 2007). Heat stress can damage proteins and membranes (Jagadish et al., 2021), disrupt enzyme

function, and impair reproduction, leading to reduced growth and yield (Bita & Gerats, 2013; Lobell & Gourdji, 2012) and elevated plant mortality (Haberstroh et al., 2022). Extreme or prolonged warming can also exacerbate pest and pathogen pressure, further compromising plant performance (W. R. L. Anderegg et al., 2015; Bebbler et al., 2013; Deutsch et al., 2018). Plants can partly acclimate to temperature by adjusting photosynthesis, respiration, and leaf traits (Atkin & Tjoelker, 2003; KATTGE & KNORR, 2007), but extreme temperatures can overwhelm this capacity, leading to carbon deficits and reduced performance (Slot & Kitajima, 2015; Way & Oren, 2010). Elevated temperatures have also been shown to negate the impacts of CO₂ fertilization on plant growth (C. Zhu et al., 2023). One of the longest running tropical forest monitoring studies, in Costa Rica, reports no CO₂-linked increase in forest productivity, and declines in forest growth during years with elevated nighttime temperatures (Clark et al., 2021).

Changes in terrestrial climate driven by elevated atmospheric CO₂ are also impacting plant water status via changes in surface relative humidity (Ficklin & Novick, 2017; Kim & Johnson, 2025; Willett et al., 2014) and rainfall patterns (Gebrechorkos et al., 2025; Kim & Johnson, 2025; Willett et al., 2014; OECD 2025) (See responses to section 6.7 on drought for further details of drought patterns). Drought and atmospheric drying decrease vegetation growth (Fu et al., 2022; Grossiord et al., 2020) and increase plant mortality (Allen et al., 2015; Bennett et al., 2015; Gazol et al., 2025; Gazol & Camarero, 2022; Hartmann et al., 2022; McDowell et al., 2022; Oliver L. Phillips et al., 2010; Senf et al., 2020), impairing the capacity of ecosystems to sequester carbon (William R. L. Anderegg et al., 2020; Canadell et al., 2021; Gatti et al., 2021; Hubau et al., 2020; Ke et al., 2024; Migliavacca et al., 2025; Peñuelas et al., 2017). The IPCC AR6 Cross Chapter Box 5.1 notes that “there is *high confidence* that the global net land CO₂ sink is reduced on interannual scale when regional-scale reductions in water availability associated with droughts occur, particularly in tropical regions. There is also *high confidence* that the global land sink will become less efficient due to soil moisture limitations and associated drought conditions in some regions for high-emissions scenarios, specially under global warming above 4°C.” Impacts of climate change on fire are covered in a different section of this response but are also relevant here.

There is a growing body of evidence — from forest observation, remote sensing and atmospheric observations — that impacts of changing climate (temperature and drought) on plants are already having observable impacts on plant health and carbon uptake at continental scales, including the United States (Schwalm et al., 2012; Williams et al., 2023), the Amazon (R. Brien et al., 2015; S. Chen et al., 2024; Gatti et al., 2021), African tropical forests (Hubau et al., 2020), the pan-tropics (Liu et al., 2023), China (Wang et al., 2025), and Europe (Forzieri et al., 2021; Fu et al., 2022; Segura-Barrero et al., 2025; van der Woude et al., 2023). Wu et al. (2025) and Wei et al. (2023) both find significantly intensified moisture controls over photosynthesis across the Northern Hemisphere and globe, respectively. Impacts of increased drought on global greenness trends was mentioned in our comments to Section 2.1.1 (X. Chen et al., 2024).

Earth system models, that simulate CO₂ fertilization effects, and atmospheric and soil moisture limitations on vegetation growth, predict that these impacts will substantially worsen under future climate scenarios (Cao et al., 2022; G. Chen et al., 2025; Cook et al., 2020; Julia K. Green et al., 2019; J. Li et al., 2024; C. Xu et al., 2019; Yang et al., 2024). Further, numerous lines of evidence suggest that the current generation of ESMs collectively underestimate numerous features of observed ecosystem drought responses (Bastos et al., 2018; J. K. Green et al., 2024; Kolus et al., 2019; Yin et al., 2025) and, while they capture CO₂ effects on photosynthesis, they typically do not include many other climate-driven hazards to plant growth and survival, including insect outbreaks (William R. L. Anderegg et al., 2015), plant hydraulic mortality (Robbins et al., 2024), lagged effects of drought on plant health (Wei et al., 2022), complex interactions between plant phenology and frost events (Lambert et al., 2022), and seed dispersal limitations to plant adaptation (Zani et al., 2023).

In summary, while CO₂ can be considered to directly stimulate leaf-level photosynthesis, this does not mean that the net effects of rising CO₂ (inclusive of climatic change) will be to promote vegetation growth and carbon uptake over longer timescale, given the associated changes to climate variability, heat stress, and atmospheric and soil droughts, which are already visible and are anticipated to worsen. This is a very extensive and high profile area of research, which the authors of the CWG have chosen to ignore entirely, instead focusing extensively on a single study on leaf level CO₂ response.

ACTION: The report authors need to acknowledge and provide substantive discussion of the fact that rising CO₂ levels will co-occur with other changes to the Earth system – namely, warming temperatures and altered weather patterns – and that collectively these co-occurring changes will not necessarily result in a net benefit to global or even U.S. plant productivity as discussed in this comment. Their response needs include the references provided in this comment. Our review of this topic is based on more than 100 references beyond those cited in the DOE CWG report, along with a previous DOE report on the effects of elevated CO₂ on ecosystems. Each one of these references deal with one or more effects of temperature, CO₂, drought, and nutrients on photosynthesis and plants from greenhouse, experimental, and modelling studies.

2.1.3. Rising CO₂ and crop water use efficiency

Page 6

Comment Type: Technical

SUMMARY OF COMMENTS IN THIS SECTION: Section 2.1.3 purports to discuss rising CO₂ and crop water use efficiency, but it bases the discussion primarily on papers that did not look at crops. Several inaccurate and misleading statements are made with regards to the cited literature, and a holistic review of the literature and topic of plant water use under CO₂-induced climate change was omitted. We do not find justification for the section's conclusions about the risk of desertification, about any implications of global studies for crop yields, or about increased

water use efficiency. We recommended revising this section to rely on studies that explicitly consider crop water use efficiency. In this section (as elsewhere), the report's authors need to improve the accuracy of their summaries of cited literature and increase the number of studies they consider so that they accurately reflect current understanding.

Page 6

Comment Type: Technical

DOE CWG STATEMENT: *"They reported that models without CO₂ fertilization predicted CWP losses in every region, but those were more than offset by CO₂ fertilization so that all regions showed a net CWP gain."*

COMMENT: The phrasing of this statement implies that the models used in the study were altered to consider CO₂ fertilization in comparison to no CO₂ fertilization. In reality, the study authors ran two different simulations, both of which modeled CO₂ fertilization. To quote the paper: "we considered two sets of simulations: the first accounting for both effects of elevated [CO₂] and changes in climate (CC w/ CO₂); the second accounting for changes in climatic conditions whilst keeping [CO₂] constant to present-day levels (CC w/o CO₂).". Thus, what changed was not the model but rather the model forcings. This is an important distinction because it demonstrates that the impact that elevated CO₂ has on water use by crops is already included in the models used by the IPCC and scientific community. It is not an aspect that has been overlooked or ignored, but included only by this one study. Instead, the study forcings were specifically designed to assess the impact of elevated CO₂ on simulated results using existing, standard models, which include CO₂ fertilization.

ACTION: Change the phrasing of this sentence to clarify that Deryng et al. (2016) does not report "models without CO₂ fertilization" but rather model simulations where CO₂ was kept constant compared to simulations where CO₂ was increased.

Page 6

Comment Type: Technical

DOE CWG STATEMENT: *"Deryng et al. (2016) also reported that negative impacts of warming on wheat and soybean yields were fully offset by CWP gains and mitigated by up to 90 percent for rice and 60 percent for maize."*

COMMENT: This statement reports only the median value found by Deryng et al. (2016), without acknowledging the large disagreement across the models considered in the paper. Between 60 and 80% of models agreed that Maize yield would decrease, while for rice and soybean less than 60% of models agreed on the sign of response of yield. Only for wheat did more than 60% of models predict that negative impacts of warming on yield could be offset. It is noteworthy that in the absence of rising CO₂, the yield changes simulated by the models tended to agree, while

yield changes simulated by the models with rising CO₂ were highly variable (see supplementary figure S6). This difference in agreement indicates that the plant response to elevated CO₂ remains uncertain. Additionally, these globally gridded crop models do not account for additional temperature driven factors impacting yield such as increases in pest pressure which are predicted to have particularly large impacts on wheat (Deutsch et al., 2018). The scientific consensus is that CO₂-induced climate change—including rising temperatures, shifting weather patterns, and altered precipitation—will outweigh the benefits of CO₂ fertilization, leading to net yield declines across major agricultural regions in the U.S. and globally (Auffhammer & Schlenker, 2014; Hsiao et al., 2019; Hultgren et al., 2025; Jägermeyr et al., 2021; Lobell et al., 2011; Lobell & Field, 2007; Muehe et al., 2019; C. Zhu et al., 2023).

ACTION: The report authors need to change this statement to clarify that the reported yield gains are the median response across the models and explicitly note that there was large disagreement among the models in terms of yield change. They also need to discuss other temperature driven negative impacts on yield that are not included in the globally gridded crop models analyzed by Deryng et al (2016) such as increasing pest pressure. They need to put the study in the context of the greater body of scientific understanding about how elevated CO₂ and CO₂-induced climate change will affect crop yields

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Comment Type: Technical

DOE CWG STATEMENT: *“Similarly, Cheng et al. (2017) noted that increased Gross Primary Production from 1982 to 2011 due to rising CO₂ uptake was accompanied by such large gains in CWP that global water use by plants had not increased, despite the extra biomass.”*

COMMENT: Cheng et al. (2017) does not assess crop water productivity defined by the report authors as “yield per unit of water used”. Cheng et al. (2017) assesses water use efficiency of the bulk land surface with no evaluation or comparison with crop yields and thus the findings are not applicable for evaluating changes in CWP. Li et al. (2023) conversely found that global ecosystem-level WUE (which is what Cheng et al. 2017 is focused on) has not increased since 2001 because of the increases in atmospheric evaporative demand (VPD), and this stalling of changes in WUE will likely continue in the future because of continued increases in VPD due to climate change.

ACTION: The report authors should remove this statement from the crop water use efficiency section as the paper cited does not evaluate crop water use efficiency. If they choose to include a discussion of Chen et al. (2017) elsewhere the report authors should also discuss Li et al. (2003) and specify that while water use efficiency does increase under water stress, actual plant water use is also subject to increased demand from the atmosphere.

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Comment Type: Technical

DOE CWG STATEMENT: *“Deryng et al. (2016) assumed that climate change would “exacerbate water scarcity”. Yet while models do predict that drylands will expand under climate warming, current data show the opposite: greening is happening even in arid areas. Zhang et al. (2024) report that due to increased CO₂ levels “increasing aridity in drylands won’t lead to a general loss of vegetation productivity”; at most only 4 percent of currently arid areas will see increased desertification.”*

COMMENT: First, again, this section is about *crop* water use efficiency, so it is misleading to highlight Zhang et al. (2024), which is about non-cropped regions.

Second, climate change indeed *has* already exacerbated water scarcity (and increased water demand) for agriculture and is projected to do so in the future (e.g. Chandanpurkar et al., 2025; Kinnebrew et al., 2025; Qin et al., 2020; Vicente-Serrano et al., 2022; Williams & Abatzoglou, 2025). Relying on studies that look at ‘greening’ is an insufficient measure of present or future water scarcity.

Third, Zhang et al. (2024) produce future projections of dryland vegetation productivity using regression relationships derived from the historical period. This is a flawed approach for projecting out of sample conditions in the future where temperatures have increased further, atmospheric dryness has increased, and the potential benefits of increased CO₂ have saturated (e.g. Grossiord et al., 2020; F. Li et al., 2023; Q. Zhang et al., 2019). Indeed, studies have shown an observed *decrease* in vegetation productivity in drylands due to increasing water constraints (Dannenberg et al., 2022; Jiao et al., 2021; Williams et al., 2023; Yuan et al., 2019).

ACTION: The report authors should remove these sentences. If they chose to discuss this topic, they need to bring in the body of literature cited in the comments to provide a more accurate depiction of topic and current understanding.

2.1.4. CO₂ fertilization benefits in IPCC Reports

Page 6

Comment Type: Technical

SUMMARY OF COMMENTS IN THIS SECTION: Section 2.1.4 suggests that the IPCC has neglected to report on global greening and CO₂ fertilization, but we explain how this is not true and direct the authors to remove misleading statements and refer to the IPCC’s work on the global carbon cycle, which includes greening and CO₂ fertilization.

DOE CWG STATEMENT: *“The IPCC has only minimally discussed global greening and CO₂ fertilization of agricultural crops. The topic is briefly acknowledged in a few places in the body of*

the IPCC 6th and earlier Assessment Reports but is omitted in all Summary documents. Overall...the Policymaker Summaries, Technical Summaries, and Synthesis Reports of AR5 and AR6 do not discuss the topic.”

COMMENT: The authors need to remove these misleading statements that imply the IPCC is intending to mask or hide the occurrence of “global greening” and “CO₂ fertilization.” The IPCC AR6 report extensively covers the trend in land carbon uptake (the net amount of carbon leaving the atmosphere and being stored in land systems), of which CO₂ fertilization is only one of many competing factors. Land carbon uptake is a key component of the global carbon cycle; it is one of the major factors that control the amount of human released CO₂ that stays in the atmosphere. The DOE report’s omission of discussion of net uptake of carbon by terrestrial ecosystems artificially excludes a large body of relevant literature. The role of elevated CO₂ in boosting land carbon uptake through enhanced photosynthesis is discussed by the IPCC in Chapter 5 in section 5.2.1.4, as well as in the summary of AR6 Ch5, but in these sections it is also weighed against the role of temperature, water stress, nutrient limitation, and changes in respiration. It is the total land carbon uptake (not just CO₂ fertilization) that determines the climate response to CO₂ emissions (described in IPCC AR6 Ch5 section 5.2.1.4.1). The expected trend of increasing but saturating land carbon uptake is described in the summary for policy makers (SPM section B.4.1) and noted in SPM Figure 7.

The Policymaker Summaries, Technical Summaries, and Synthesis reports are written to condense and reduce the jargon-heavy and technical main body of the IPCC report and highlight the most pertinent and relevant portions for policymakers. The fact that “global greening” and “CO₂ fertilization” are not explicitly mentioned in these summaries and synthesis reports reflects the fact that the specific impact of “global greening” and “CO₂ fertilization” were not relevant on their own for informing policies and decisions under consideration by policymakers. As previously discussed, global greening and CO₂ fertilization together are only one aspect of many competing factors that collectively determine the net effect that increasing CO₂ has on the land carbon sink, and trends in the net land carbon uptake are discussed in the Summary for Policy Makers (section B.4.1 and SPM Fig. 7). The IPCC reports are not hiding or masking the occurrence of global greening or the role of CO₂ fertilization. The text cited by the authors of this report note that the IPCC concluded “with high confidence” that greening has occurred, but that there is “low confidence in the magnitude of the trend.”

ACTION: The authors need to remove the misleading statements that imply the IPCC is intending to mask or hide the occurrence of “global greening” and “CO₂ fertilization”. The report authors also need to include discussion of how all of the components of the terrestrial carbon budget, not just plant photosynthesis, as well as the net uptake of carbon by terrestrial ecosystems will be impacted by CO₂-driven climate change.

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Comment Type: Technical

DOE CWG STATEMENT: “There are also brief mentions of CO₂ fertilization effects and improvements in water use efficiency in a few other chapters in the AR6 Working Groups I and II Reports.”

COMMENT: There is an entire cross working group box describing changes in water use efficiency driven by CO₂ (cross chapter Box 5.1), which is substantial and should not be classified as “brief”.

ACTION: The report authors should specifically refer to this cross working group box and remove the word “brief”, or remove this statement entirely.

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Section 2.2.1: Changing pH

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This is a **technical comment on Section 2.2.1**

Chapter 2 of the DOE CWG report addresses the topic of The Alkaline Ocean. The chapter contains critical omissions and factual errors, as noted below:

Page 7, Paragraph 1, Sentences 2-4

Page 8, Paragraph 3, Sentences 1-4

Technical Comment

The authors' comparison between past and current ocean pH levels is fundamentally flawed because it ignores a central aspect of ocean carbonate chemistry: the timescale of responses in pH and carbonate saturation to a change in carbon dioxide (CO₂) concentration. Comparing past and current pH requires distinguishing between long-term steady states and transient changes, as natural long-term changes in ocean pH have a fundamentally different impact on ocean chemistry than the rapid input of carbon from fossil fuels (see Hönisch et al., 2012; Zeebe et al. 2016). When ocean pH is lowered rapidly (e.g. over 10s to 100s of years), the abundance of carbonate ions decreases rapidly. These carbonate ions are the most critical ingredient for marine shell formation, and thus shells become harder to grow. Technically, this is known as a drop in calcium carbonate saturation state, and it makes calcium carbonate shell formation more energetically costly (e.g. Gagnon et al., 2021). In contrast, when ocean pH is lowered slowly (e.g. over 1000s of years or more), the dissolution of seafloor calcium carbonate, alongside weathering of rocks on land, has a buffering effect on ocean saturation state. This allows shell formation to continue unimpeded despite the lower pH. Indeed, the alkalinity balance (not just pH) helps determine whether CaCO₃ is stable. Over geologic time, weathering and dissolution can deliver enough alkalinity to keep the ocean saturated with respect to CaCO₃, allowing shells and reefs to form, even in a “high CO₂, low pH” world (Kump et al., 2009).

Today, anthropogenic CO₂ emissions are lowering ocean pH on decadal to centennial timescales, which are too rapid for these buffering processes to keep up with, resulting in lower calcium carbonate saturation states, and making shell formation more energetically costly and enhancing environmental stress on these organisms.

Consequently, the comparisons of Precambrian (Krissansen-Totton et al., 2018) and even the last deglaciation (Rae et al., 2018) ocean pH and marine life are *not* suitable analogs for understanding the effects of future ocean acidification, as has been demonstrated by the scientific community (Hönisch et al., 2012).

Page 7, Paragraph 1, Sentence 1
Technical Comment

The authors' discussion of "ocean acidification" as an incorrect term is additionally misleading.

As a linguistic point, a substance does not need to be acidic to undergo acidification, just as deforestation can occur in a region that is mostly forest, melting can occur for an ice cube that is not fully melted, or light dimming can occur in a room not fully dark. More substantively, neutral pH simply refers to the condition when hydrogen ions [H⁺] and hydroxide ions [OH⁻] are in equal concentration, although the pH where this occurs (e.g., 7.0) depends on other variables such as temperature, and it should not be viewed as a magic number in which a system's behavior suddenly changes. In humans, severe health complications can emerge for "low" blood plasma pH levels that are nonetheless higher than 7.0 (Jung et al., 2011). Similarly, disruption to carbonate chemistry critical for organisms like corals and shell-builders can occur for pH changes that do not cross the "7.0" threshold.

Acidification refers to an increase in hydrogen ion concentration ([H⁺]) regardless of whether the solution remains alkaline (pH >7.0) (Wang and Katz, 1965; Malan et al. 1985). This terminology is used outside climate science, for example in disciplines such as medicine, animal physiology, and plant physiology (e.g., Tarnow et al. 1975; Cheung et al. 1982; Malan et al. 1985; Raven, 1985), studies of changes to the pH of blood (e.g. Van Slyke, 1921), changes in pH of urine, bile, liver, heart, and pancreatic fluid (Malan et al. 1985). Note that these examples include studies that were published before ocean acidification was widely recognised. An alternative term used is acidosis (e.g. Wang and Katz, 1965). The statement's dismissal of "ocean acidification" ignores its widespread use and acceptance in scientific literature (e.g. Pörtner et al. 2004; Gattuso et al. 2015).

"Ocean acidification" became the more commonly used term for the phenomena of ocean carbonate chemistry changes because it provides a straightforward terminology for describing the declining pH of the ocean. It is not used in a way to indicate that the ocean is becoming an acid. In one of the first peer reviewed papers to document this process, Caldeira and Wickett (2003) describe both the process of declining pH as well as the context provided by the geologic record that indicates that the changes in ocean chemistry occurring today are large and very rapid compared to other times in Earth's history.

Page 7, Paragraph 1, Sentence 2

Technical Comment

The authors' claim that most ocean life evolved at a time when oceans were more acidic.

Comparison between past and current ocean pH also lacks fundamental context. The reference to Krissansen-Totton et al. (2018) shows that the oceans may have been more acidic when atmospheric CO₂ concentrations were very high in Earth's early history, but there was no complex multi-cellular life (Knoll et al., 2011) and certainly no animals with skeletons requiring calcium carbonate (Knoll and Nowak, 2017). The Earth's ocean 2.5 billion years ago would be a very hostile environment to much of today's biodiversity, just as the atmosphere was also almost devoid of oxygen (Luo et al. 2016) and would be toxic to modern ecosystems. The earliest evidence of significant CaCO₃ biomineralisation is 550 million years old (Murdock, 2020). Therefore, the pH conditions "in which life evolved", billions of years ago, is irrelevant for evaluating whether current or near-future conditions are suitable for modern ecosystems to continue (Pörtner et al. 2004; Halevy and Bachan 2017).

Modern marine life and ecosystems (e.g. coral reefs and open ocean fisheries) are very different from the initial lifeforms that evolved in the earliest oceans (e.g. bacteria, single-celled organisms), and so have different adaptive ranges and vulnerabilities. In the same way that the environmental conditions that were suitable for dinosaurs have little relevance for optimal conditions for humans, there is little relevance in comparing early ocean bacterial habitats to the conditions to which modern marine life has adapted. As discussed above, long term geological pH changes are not a good analogue for a rapid drop in pH of the type happening today, for the key reason that a rapid pH drop results in lowered calcium carbonate saturation state, which makes shell formation harder (e.g. Hönisch et al., 2012). To find better analogues for modern pH decline in the geological record, we need to look at times when ocean pH declined quickly, for example at the end-Triassic mass extinction (Trudgill et al., 2025). In fact, every major ocean mass extinction event for which we have pH reconstructions shows that a rapid drop in ocean pH accompanied the mass extinction event (Trudgill et al., 2025). The geological record thus suggests that rapid pH decline, as is occurring today, is a matter of serious concern for marine ecosystems and the communities and economies which they support.

Page 7, Paragraph 1, Sentence 3

Technical Comment

The use of "ocean pH" in this statement is misleading, as it seems to imply whole ocean pH or (following from the text above) the pH of the surface ocean, whereas the boron isotope study referenced here applies only to the deep Southern Ocean. These are completely different habitats occupied by completely different species. The habitats of most concern with respect to ocean acidification are in the surface (e.g. coral reefs, key

fisheries), where pH was higher than today during the last ice age as reconstructed by numerous studies (e.g. Hönisch and Hemming, 2005; Foster, 2008; Martínez-Botí et al., 2015; Ezat et al., 2017; Shao et al., 2019; Shuttleworth et al., 2021), not lower as suggested here. The authors must revise this text to clearly define the specific pH metric *and* the location to which it refers (whole ocean, surface ocean, deep ocean, etc.) and cite the appropriate reconstructions of that pH metric over geologic time.

The authors also state that “*Thus, ocean biota appear to be resilient to natural long-term changes in ocean pH since marine organisms were exposed to wide ranges in pH,*” which considering the scientific literature as a whole is a factual error. Several meta analyses have documented large scale and pervasive impacts of ocean carbonate chemistry change across multiple taxonomic groups, especially in marine calcifiers (e.g., Kroeker et al., 2010; Bednarsek et al., 2019; Figuerola et al., 2021). Recent articles have also highlighted the persistence or tolerance of some species under declining pH conditions, and variability in responses to changing chemistry, both of which provide insights into potential for adaptation and marine biodiversity in the future (e.g., Hendricks et al., 2010; Chan and Connolly, 2013; Leung et al., 2022). In summary, a more balanced review of this topic would acknowledge that there are clearly negative consequences for some marine taxa, although perhaps not all. In addition, many of the taxa of concern are also commercially/economically valuable (for example, shellfish).

Technical Comment/ Omission

The only mention of the oceans throughout the entire report is in the context of ocean acidification, coral reefs, and sea level rise. The glaring omission of the myriad impacts of climate change on the ocean - marine heat waves, changing species distributions, changes in ocean circulation, increased harmful algal blooms, coastal erosion, and economic impacts on commercially valuable fisheries to name a few - is a significant problem with the report (see, for example: Wood et al., 2003; Fu et al., 2012; Mills et al., 2012; Le Bris et al., 2018; Gobler et al., 2020; Weiskopf et al., 2020; Paukert et al., 2021). To fix this, the authors should add a section describing these other impacts of climate change on the ocean.

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Response to DOE Section 2.2.2: Coral reef changes

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- **Page:** 7, section 2.2.2, paragraph one, sentence one
- **Comment Type:** Technical
- **Comment:**

The first sentence of the first paragraph of 2.2.2 states: "There are concerns that a decreasing pH of sea water will reduce the calcification rate of coral reefs".

This description fails to acknowledge that concerns that a decreasing pH of sea water will reduce the calcification rate of coral reefs are due to inferences based on significant and well established empirical evidence that decreasing pH is already reducing the calcification rate of coral reefs (Orr et al. 2005; Hofman et al. 2010; Barkley et al. 2015; Albright et al., 2018). A recent meta-analysis of 83 studies (1998–2020) quantifies a global decline in coral reef calcification rates averaging $4.3\% \pm 1.9\%$ per year, directly linked to decreasing pH (from ~8.2 to ~8.04) and warming (Cornwall et al. 2021). It includes both field data from long-term monitoring (e.g., Great Barrier Reef, Caribbean) and experimental studies (Cornwall et al. 2021). It concludes that there is a low likelihood that the world's coral reefs will maintain their functional roles (e.g. coastline protection, hot spots of biodiversity, value for tourism) without near-term stabilization of atmospheric CO₂ emissions.

- **Fix:**

This context should be included.

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- **Page:** 7, section 2.2.2, paragraph one, sentence two
 - **Comment Type:** Technical
 - **Comment:**

The second sentence of the first paragraph of 2.2.2 states: "coral reefs already endure large swings in pH, partly due to daily photosynthetic activity in the reef; measured pH values range from 9.4 during the day to 7.5 at night (Revelle and Fairbridge, 1957).".

This statement implies that coral reefs will be resilient to current and future decreases in pH as they already experience variation in pH. However, this statement ignores the fact that these values are a single example taken from "reef pools" in Western Australia and were associated with changes in temperature and evaporation. The same sentence in the same reference (Revelle and Fairbridge, 1957: page 279) states that "the adjacent sea remained 8.2". Therefore, it is clearly inappropriate to imply that a range of 9.4-7.5 is representative of pH variation in coral reefs as a whole. More extensive recent studies conducted on the Hawaiian archipelago show that daytime variation in pH is less than 0.5 (Guadayol et al. 2014). Moreover, changes in overall ocean pH will shift the entire range of variation towards a lower range with a more extreme minima, a minima which will impact modern reef organisms such as corals and bivalves (Albright et al., 2018; Cornwall et al. 2021). Although specific studies have documented the resilience of corals in a few locations to changes in pH (e.g., Jury and Toonen 2019), the bulk of the scientific evidence does not support this type of resilience (Barkley et al., 2015). Also such resilience may not manifest when combined with increases in temperature (Guillermic et al. 2021). Regional variations in ocean pH do exist, e.g. due to variation in local upwelling (Great Barrier Reef, Caribbean, Indo-Pacific, Red Sea) but these tend to be associated with regional variations in calcification (Cornwall et al. 2021). Regions with lower pH also show lower rates of calcification (Cornwall et al. 2021). Regions with lower pH (e.g. CO₂ vent sites in Indo-Pacific) also exhibit lower calcification. As stated in Barkley et al (2015): "a comparison of the naturally low-pH coral reef systems studied so far revealed increased bioerosion to be the only consistent feature among them, as responses varied across other indices of ecosystem health."

- **Fix:**

This additional evidence and context should be included.

-
- **Page:** 7, section 2.2.2, paragraph one
 - **Comment Type:** Technical
 - **Comment:**

The final sentence of the first paragraph of 2.2.2 states: "But Ridd et al. (2013) showed that report to have resulted from a biased data analysis that, when corrected, showed no change in calcification rates. Nevertheless, the alarm produced by the original paper has persisted as evidenced by the large number of published citations (541) to the original study compared to only 11 citations to the correction (as of 30 April 2025)".

As a correction of fact: Ridd et al. (2013) actually has 20 citations according to Google Scholar (as of 14 August 2025). Moreover, some of these citations are by studies that directly criticise its inferences (De'ath et al. 2013; Schaffelke et al. 2018).

More importantly, although Ridd et al. (2013) did correctly identify the outermost bands of corals were incompletely formed, and therefore under-estimated, in De'ath et al. (2009), applying this correction only alters the estimate of the decline in calcification over the period 1990–2005 from 14.2% to 11.4%. The suggestion that the data shows "no change in calcification rates" is false and is based on erroneous assumptions about ontogenetic variation that aren't supported by independent observations (De'ath et al. 2013). The updated decline of 11.4% (0.76% yr⁻¹) is still relatively high (De'ath et al. 2013) and subsequently studies of Porites corals have found similar estimates ~13 % (e.g. Guo et al. 2020).

Importantly, comparison of annual calcifications among century-scale datasets shows that the frequency of coral growth anomalies has increased in multiple regions since the late 1990s (Lough and Cantin, 2014). Again, a recent meta-analysis of 83 studies (1998–2020) quantifies a global decline in coral reef calcification rates averaging 4.3% ± 1.9% per year, directly linked to decreasing pH (from ~8.2 to ~8.04) and warming (Cornwall et al. 2021).

- **Fix:**

This additional evidence and context should be included.

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- **Page:** 7, section 2.2.2, paragraph two
 - **Comment Type:** Technical
 - **Comment:**

The second paragraph of 2.2.2 states: "The most recent annual summary of GBR conditions from the Australian Institute of Marine Science indicates that coral production has rebounded strongly (AIMS, 2023). Figure 2.4 shows the results of the AIMS surveys of hard coral cover, expressed as a percentage of the reef area."

It has been previously documented that hard coral cover as a metric is a poor representation of ecosystem health or diversity (Bruno et al. 2009; Hughes et al. 2018a). High coral cover on the GBR is driven by fast-growing *Acropora* corals, which may mask the loss of other species (Hughes et al. 2018a).

The latest AIMS survey shows that, in 2025, 48% of surveyed reefs underwent a decline in percentage coral cover, 42% showed no net change, and only 10% had an increase (AIMS 2025). Reefs with stable or increasing coral cover were predominantly located in the Central GBR (AIMS 2025). Regional declines ranged between 14% and 30% compared to 2024 levels, with some individual reefs experiencing coral declines of up to 70.8% (AIMS 2025).

- **Fix:**

This additional evidence and context should be included.

- **Page:** 7, section 2.2.2, paragraph two
- **Comment Type:** Reference
- **Comment:**

The final sentence of the second paragraph of 2.2.2 states "the rebound has surprised some observers." without a single citation to support this statement.

- **Fix:**

There is no citation which supports this statement. One should be provided.

- **Page:** 8, Figure 2.4
- **Comment Type:** Technical
- **Comment:**

Figure 2.4 shows "hard coral cover, expressed as a percentage of the reef area". However, the data presented ends in 2023 when data up to 2025 are available (AIMS 2025). The two additional years worth of data should be included.

- **Fix:**

Please update the plot of data.

- **Page:** 8, section 2.2.2, paragraph 3
- **Comment Type:** Technical
- **Comment:**

The third paragraph begins "It is being increasingly recognized that publication bias (alarming ocean acidification results preferred by high-impact research publications) exaggerates the reported impacts of declining ocean pH."

This sweeping statement is supported with reference to one publication from 2016 (Browman, 2016; note that the pages for this publication are "529–536" not "1–536"). While this publication does state "As is true across all of science, studies that report no effect of ocean acidification are typically more difficult to publish" it also states that research on ocean acidification "has clearly matured" and openly calls "for a heightened level of organized (academic) scepticism to be applied". A more recent and more detailed review of the literature is available (Connell and Leung, 2023). This meta-analysis of 373 studies across 24 years, concludes that although there is a decline in negative effects of ocean acidification as more studies are conducted, this pattern is due to improved experimental designs, adaptation in some species, and a broader range of taxa studied. Overall, the effects of ocean acidification are still negative particularly on calcification in corals and bivalves, skeletal mineralization in fish, and fish behavior.

- **Fix:**

This additional evidence and context should be included.

- **Page:** 8, section 2.2.2, paragraph 4
- **Comment Type:** Technical
- **Comment:**

The fourth paragraph refers to meta-analysis (Clements et al., 2021) of the negative effects of ocean acidification on reef fish behavior. However, the report does not mention work done since which cautions against "throwing the baby out with the bathwater" (Esbaugh 2023) particularly given that fish also have to deal with the effects of ocean warming (e.g. Pistevos et al. 2017).

Furthermore, although the negative effects of ocean acidification on reef fish behavior may be less negative than previously inferred, there remains significant evidence that ocean acidification impacts the health of fish larvae (e.g., increased mortality, altered energy budgets) and the habitats of habitat-dependent species (e.g., coral reef fish) (Di Santo, 2019; Siegfried and Johnson 2023; Priest, et al. 2024). Also large scale experiments involving multiple levels of the food web (algae + herbivorous invertebrates + predatory fish) show that increases in pH and temperature disrupt ecosystem dynamics (Goldenberg et al. 2017).

- **Fix:**

This additional evidence and context should be included.

- **Page:** 7, section 2.2.2, paragraph 5
- **Comment Type:** Technical
- **Comment:**

The first and second sentence of the last paragraph of 2.2.2 states "In summary, ocean life is complex and much of it evolved when the oceans were acidic relative to the present. CO₂ levels for more than 200 million years afterward were many times higher than they are today." This summary conclusion is not justified by the previous content. It is misleading in a number of ways.

Ocean life did evolve when oceans were acidic but this was over 2.5 billion years ago when the only life in existence was single celled cyanobacteria and early eukaryotes. There were no multicellular animals (metazoans), and certainly no animals with skeletons requiring calcium (Knoll & Nowak, 2017). The Earth of 2.5 billion years ago would be unable to support much of today's biodiversity. Therefore, the pH conditions "in which life evolved", billions of years ago, is irrelevant for evaluating whether current or near-future conditions are suitable for modern ecosystems to continue (Pörtner et al. 2004; Halevy and Bachan 2017).

Corals and reefs have undergone several extinctions and diversifications over their geological history and much of this disruption may have been due to rapid changes in ocean pH (Kiessling and Simpson, 2011). There have been five major extinction events in the past 260 million years impacting reefs and four of those coincide with evidence for ocean acidification plus warming (Kiessling and Simpson, 2011):

1. Permian–Triassic (251 Ma)
2. Triassic–Jurassic (199.6 Ma)
3. Early Jurassic (183 Ma)
4. Paleocene–Eocene (55.8 Ma)

These disruptions include both variations in reef volume and significant shifts in taxonomic representation (Kiessling and Simpson, 2011; Pandolfi and Kiessling, 2014).

The content of this section mentions corals and fish focuses but beyond general statements ignores other organisms critical to reefs. It completely ignores the significant impacts of ocean acidification on bivalves (Pfister et al. 2016; Bullard et al 2021) which are important as both commercial seafood and for protecting shorelines (van der Schatte Olivier, 2020). In 2020, bivalve mollusks accounted for ~17 million tonnes of aquaculture production (21% of total aquaculture), valued at billions of USD annually (FAO 2022). Oyster and mussel reefs (bioherms) reduce coastal erosion and enhance resilience to storms (Beck 2011; Gentry et al. 2019; van der Schatte Olivier, 2020). Also ignored are pteropods, shelled organisms that are key components of ocean food chains (that involve commercially important fish such as herring and salmon) and appear particularly sensitive to ocean acidification (Bednaršek et al. 2021). A meta-analysis synthesizes data from 27 studies (2010–2021) and found a ~20–40% shell dissolution at pH ~7.8 (Bednaršek et al. 2021).

- **Fix:**
- This additional evidence and context should be included.

- **Page:** 7 and 8, section 2.2.2 as a whole
- **Comment Type:** Technical
- **Comment:**

This section on "coral reef changes" fails to mention the increase in frequency and severity of coral bleaching events due to increase in ocean surface temperatures. Indeed, the entire DOE report avoids addressing this topic despite there being numerous scientific studies that do (e.g. Hughes et al. 2018b; da Silva et al. 2025; Doherty et al. 2025). One large analysis of bleaching records (100 globally distributed reef locations) from 1980 to 2016 found that the median return time between pairs of severe bleaching events has decreased since 1980 and is now only 6 years (Hughes et al. 2018b). This result suggests that the interval between bouts of coral bleaching is too short for a full recovery of mature assemblages. This increase in bleaching frequency is mainly due to warmer sea surface temperatures (Hughes et al. 2018b). Indeed, NOAA just released an updated assessment (https://www.coralreefwatch.noaa.gov/satellite/research/coral_bleaching_report.php) of the current global scale bleaching event, which represents a new record for its impact, with an estimated 84% of corals impacted by extreme and prolonged heat. As a whole, this section leaves the impression that ocean acidification is the only threat from anthropogenic greenhouse gas emissions, whereas in fact ocean warming is the primary threat.

- **Fix:**
- The ongoing impacts of human-caused warming on global reefs should be discussed in this section, given its relevance to "coral reef changes".

- **Page:** 7 and 8, section 2.2.2 as a whole
- **Comment Type:** Technical
- **Comment:**

This section focuses on the impact of ocean acidification on coral reefs, but the impacts of anthropogenic climate change on marine ecosystems extend far beyond this arena, yet are not considered in this entire assessment. Chief among these impacts are marine heat waves, which have had a profound impact on ecosystem services and economies around the world. For instance, the economic toll of the 2013-2016 marine heat wave ('The Blob') that impacted coastal economies from Alaska to California ran into the hundreds of million dollars (Smith et al., 2021).

Fix:

The report should add a new section on the impacts of human-caused climate change on marine ecosystems, including coral reefs.

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Assessment of Chapter 3 “Human Influences on the climate”

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Executive Summary

This assessment critically reviews Chapter 3 of the DOE report, "Human Influences on the Climate," identifying key misrepresentations of climate science:

1. **Misrepresentation of Climate Scenarios:** The DOE report misrepresents IPCC climate scenarios as predictions, rather than "what-if" tools, and falsely claims emissions projections consistently overstated trends in past scenario exercises.
2. **Downplaying Human Influence:** The report unjustifiably downplays human impact on warming, overstating solar influence and falsely suggesting human emissions are merely additive to natural variability.
3. **Flawed Understanding of Carbon Sinks:** The DOE report shows a misleading account of carbon sinks, omitting crucial information on their future limitations, which fosters false complacency.
4. **Inaccurate Urban Heat Island Assessment:** The report incorrectly suggests urbanization significantly biases global temperature data, despite the consistency of evidence showing minimal impact from the Urban Heat Island effect.
5. **Selective Literature Review:** The DOE report selectively presents non-consensus views, failing to offer a balanced scientific discussion and leading to a distorted representation of climate science.
6. **Selective Presentation of Data:** The report's treatment of atmospheric CO₂ concentrations omits relevant scientific data, and the misleading graphical choices undermine the report's claims of comprehensive and unbiased review, instead reinforcing a false narrative that downplays the scale of recent atmospheric changes and the degree to which those changes are attributable to human activities.

Introduction

This section critically reviews Section 3 ("Human Influences on the Climate") of the DOE report "A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate" (DOE CWG) by providing an assessment of summary statements, with reference to the wider chapter. It identifies key factual errors, instances of selective evidence presentation (cherry-picking), and issues with reference interpretation. We frame our assessment in sections, structured as responses to the key summary statements proposed by the authors of Chapter 3 of the CWG.

Our assessment highlights **the DOE CWG's misinterpretation of what scenarios are, how they are intended to be used, and how they have been used in assessments** such as those reported by the Intergovernmental Panel on Climate Change (IPCC). The IPCC's use of scenarios is an acknowledgment of the inherent unpredictability of long-term socio-economic trends. The DOE report ignores this foundational principle and instead selectively focuses on high-end emissions scenarios, like RCP8.5, portraying them as failed predictions, to argue that the risks of climate change are exaggerated [see discussion of RCP8.5 on **page 15 in the CWG**]. This selective focus not only misrepresents the IPCC's methodology but also fundamentally misunderstands the role of scenario analysis in navigating complex and uncertain future challenges, a standard practice in any form of robust risk assessment.

The DOE highlights critiques of the highest emission scenarios from prior assessments which now exceed observed emissions, and these concerns are valid but uncontroversial - given that these scenarios are now generally considered to be outdated projections of coal-intensive futures. In cases where researchers have used RCP8.5 as a simple prediction of future emissions - this critique is valid.

The report maintains, however, that "RCP8.5 was misused not only by individual researchers, but also by influential science agencies like the IPCC and the U.S. National Climate Assessment (USNCA)" [direct quote from **page 15 in the CWG**]. In stark contrast, the IPCC has been consistently and explicitly clear throughout its assessment reports that **scenarios are not predictions. They are exploratory tools**—coherent and plausible "what-if" stories—designed to investigate a wide range of potential futures and the consequences of different societal choices, particularly under conditions of "deep uncertainty" where assigning probabilities to future human actions is not feasible.

The DOE report's treatment of atmospheric CO₂ concentrations further exemplifies its **selective presentation of evidence**. By focusing solely on Mauna Loa data since 1958 and manipulating visual representations [see Section 3.1.2 on **page 13** and Figure 3.1.3 on **page 14**], the report obscures critical historical context, such as the **dramatic acceleration of CO₂ growth rates since the mid-20th century**, the overwhelming dominance of fossil fuel emissions over land-use change, and the fact that current CO₂ levels are far outside the natural variability of the past 805,000 years. The omission of earlier scientific data and the misleading graphical choices undermine the report's claims of comprehensive and unbiased review, instead reinforcing a narrative that downplays the scale and human attribution of recent atmospheric changes.

Furthermore, **the report presents a fundamentally flawed understanding of natural carbon sinks**, misrepresenting their role in mitigating human-induced climate change. It misleadingly

compares human emissions to natural exchanges without acknowledging that human activities disrupt the system's long-term balance [see **page 18**, where the CWG states that human emissions are "only about 5 percent of the annual exchange"]. Crucially, **the report conflates the *absolute magnitude of carbon uptake by land and ocean sinks with their fractional uptake***, ignoring that for effective mitigation, the fractional uptake would need to increase, and this increase is not occurring. The narrow focus on historical trends neglects substantial scientific literature on the future behavior and inherent limitations of these sinks, particularly the decreasing capacity of the ocean due to buffering and warming, as well as land sink constraints due to nutrient limitations and temperature effects. These omissions downplay the urgency of emission reductions and thereby foster a misleading sense of complacency.

Responses to Summary Statements

Comment 1: On the Cause of Recent Warming

Reference in CWG Report: Page 11 (Summary Statement).

Comment Type: *Technical*. This addresses the scientific framing of human influence.

Summary statement from CWG Report: "The global climate is naturally variable on all time scales. Anthropogenic CO₂ emissions add to that variability by changing the total radiative energy balance in the atmosphere".

Comment:

This statement is a *partial truth* that omits crucial context regarding the magnitude and primary driver of recent climate change. While natural variability exists on all timescales, the IPCC AR6 and NCA5 unequivocally state that human activities have caused the observed global warming since the industrial era. The increase in atmospheric CO₂ and other greenhouse gas emissions from human activities is the dominant driver of the observed global surface temperature increase, not merely an additive factor to natural variability. For example, NCA5's (USGCRP, 2023) Key Message 3.1 directly states, "Human Activities Have Caused the Observed Global Warming", and Figure 3.1 in NCA5 explicitly attributes observed temperature change since 1850-1900 primarily to total human influence, with natural drivers showing a near-zero contribution. The Indicators of Global Climate Change (Forster et al., 2025) similarly tracks and attributes human-induced warming, noting that "generally, whatever methodology is used, on a global scale, the best estimate of the current level of human-induced warming is (within uncertainty) similar to the observed global surface temperature change."

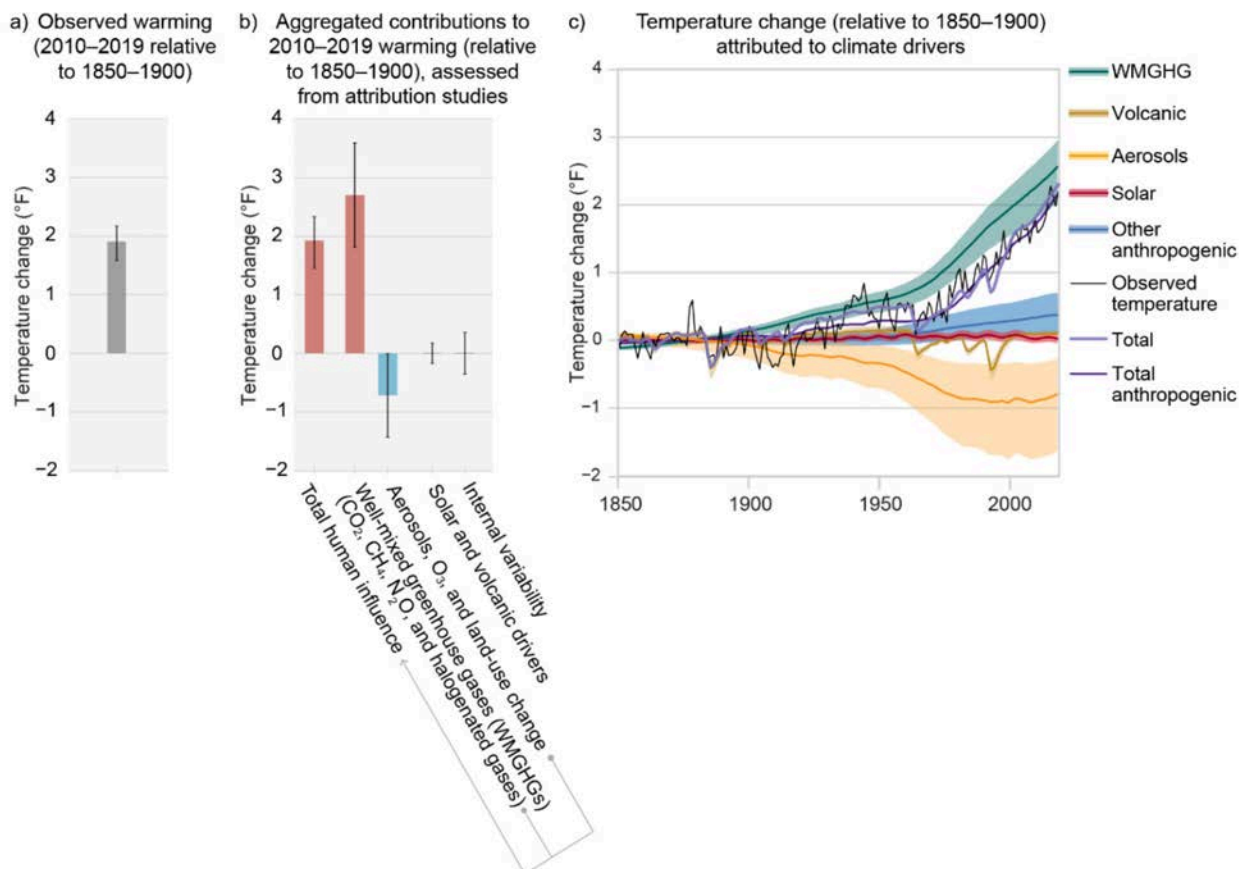


Figure 1: From (USGCRP, 2023) - showing (a) observed global average surface temperature change in 2010–2019 relative to 1850–1900; (b) temperature change over the same period attributed to total human influence, including greenhouse gases (CO₂, CH₄, N₂O, and halogenated gases), aerosols, ozone (O₃), and land-use change, as well as solar and volcanic drivers and natural climate variability; and (c) the time evolution of observed temperature (2010–2019, relative to 1850–1900; black line) attributed to different climate drivers from 1850 to 2019, including total human influence (purple line) and combined natural and human influence (lavender line). Whiskers in (a) and (b) show the very likely range, while shaded uncertainty bands in (c) show very likely (5%–95%) ranges.

Comment 2: On the Role of Natural Influences

Reference in CWG Report: Page 11 (Summary Statement); pp. 12-13 (Detailed Argument).

Comment Type: *Technical / Reference.* This comment challenges the original chapter’s scientific conclusion and its selective use of sources.

Original Text/summary statement from CWG Report: "The IPCC has downplayed the role of the sun in climate change but there are plausible solar irradiance reconstructions that imply it contributed to recent warming".

Comment:

This summary statement misrepresents the scientific consensus on solar influence. The report highlights the work of (Connolly et al., 2021), which argues that the scientific consensus on climate change attribution is premature [see citation and discussion of (Connolly et al., 2021)) on **pages 12 and 13 in the CWG.**] They contend that by selecting specific datasets—namely, a "high solar variability" reconstruction of the sun's output and a "rural-only" surface temperature record that shows less warming—one can conclude that most of the observed warming in the Northern Hemisphere since the 19th century could be attributed to natural solar activity. This approach is intended to demonstrate that the level of uncertainty in key climate data is high enough to undermine the IPCC's confident statements about human-caused warming. However, the statistical methods used in (Connolly et al., 2021) have been heavily critiqued. (Richardson and Benestad, 2022) found that their approach is highly sensitive to the order of analysis in the sequential regression used, and that the anomalously high solar influence seen in some datasets could be demonstrated to be an artifact of improper processing.

IPCC AR6 and NCA5 explicitly include solar and volcanic activity as natural drivers of climate change (Forster et al., 2023; USGCRP, 2023). In contrast to the DOE report, the IPCC's conclusions are not based on a single analysis but on a comprehensive synthesis of many studies across multiple, independent lines of evidence, including energy budget analyses (Loeb et al., 2021), climate model simulations (Gillett et al., 2021), and the physical "fingerprints" of warming such as a cooling stratosphere (Santer et al., 2017)). This robust, multi-faceted process leads the IPCC to conclude unequivocally that human activities are the dominant cause of observed warming, with the net contribution from natural drivers like the sun being negligible over the long term.

Both IPCC AR6 and NCA5 consistently conclude that natural forcings have had a negligible, near-zero, or even slightly cooling effect on global surface temperature since 1850-1900, particularly when compared to the warming from anthropogenic greenhouse gases. NCA5 Figure 3.1c illustrates that the contribution from solar and volcanic drivers has been minimal compared to anthropogenic factors over the industrial era. The most recent Indicators of Global Climate Change paper (Forster et al., 2025) further supports this finding, showing that natural forcings contributed only 0.05 °C [−0.1 to 0.2] °C to observed warming in 2010–2019, while anthropogenic forcings contributed 1.09 [0.9 to 1.3] °C (see Figure 2). The DOE report's citation of (Connolly et al., 2021) as implying the IPCC's consensus on solar forcing was "formulated prematurely through the suppression of dissenting scientific opinions" [direct quote from **page 13** of the CWG] is an instance of cherry-picking a non-consensus view and misrepresenting the thoroughness of IPCC assessments. IPCC reports consider a wide range of published literature, and their conclusions reflect the overwhelming weight of evidence.

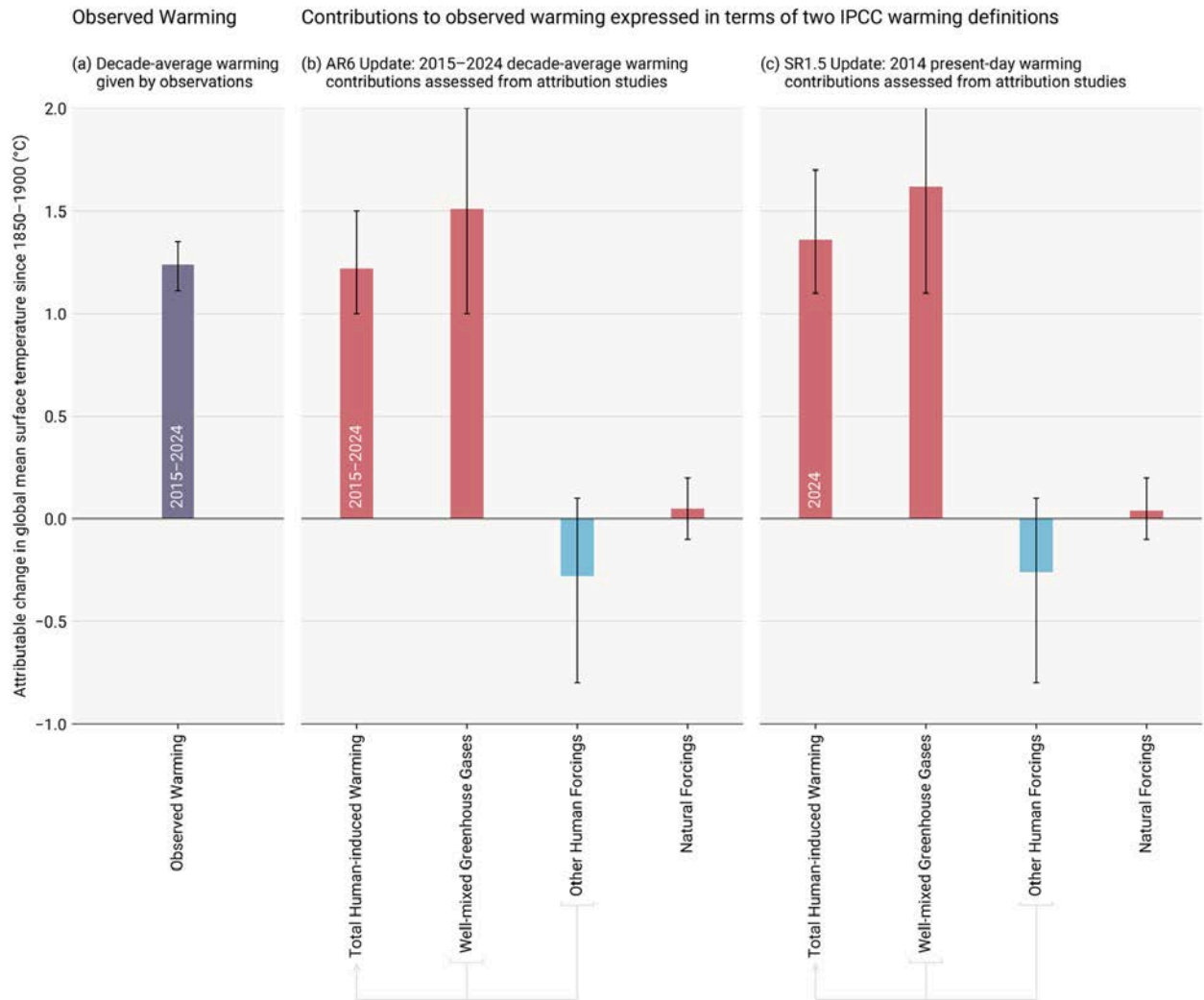


Figure 2 - from (Forster et al., 2025), showing the assessed contributions to observed warming relative to 1850–1900. The 2015–2024 average and 2024 results are this year's updated assessments for AR6 and SR1.5, respectively. Panel (a) shows updated observed global warming from Sect. 7, expressed as total global mean surface temperature (GMST), due to both anthropogenic and natural influences. Whiskers give the “very likely” range. Panels (b) and (c) show updated assessed contributions to warming, expressed as global mean surface temperature (GMST), from natural forcings and total human-induced forcings, which in turn consist of contributions from well-mixed GHGs and other human forcings. Whiskers give the “likely” range.

Comment 3: On the Use of Climate Scenarios

Reference in CWG Report: Page 11 (Summary Statements); pp. 14-16 (Detailed Argument).

Comment Type: Technical. This addresses the report's misinterpretation of the purpose of climate scenarios.

Original Text/summary statement from CWG Report: "Climate projections are based on IPCC emission scenarios that have tended to exceed observed trends. Most academic climate impact studies in recent years are based upon the extreme RCP 8.5 scenario that is now considered implausible; its use as a business-as-usual scenario has been misleading."

Comment:

This statement is an example of **selective presentation of evidence and misrepresentation of scenario purpose**. While it is true that some past high-end emission scenarios, like RCP8.5, have been critiqued for representing their high emissions pathways as a "business-as-usual" assumption (Hausfather and Peters, 2020a, b), the DOE report fails to accurately convey the nuanced role of high-emissions scenarios in climate science. The CMIP6 ScenarioMIP (O'Neill et al., 2016), which informed the IPCC-AR6 assessments, explicitly introduced "scenarios describing **possible** future developments of anthropogenic drivers of climate change," which, as such, are not forecasts. High-end scenarios explore the possible impacts of tipping points and how large the climate change risks to which society may have to adapt might be.

Each generation of ScenarioMIP has included several scenarios, one of which in each case represents the upper plausible bound to inform the 'worst-case' scenario for climate adaptation. This upper bound shifts as understanding evolves. For the CMIP5 effort which informed IPCC-AR5, this scenario was RCP8.5 (Riahi et al., 2011) but the assessment of the upper bound changes with each cycle of CMIP and IPCC reports, as technologies, economic factors and geopolitical influences evolve. The high-end scenario in ScenarioMIP CMIP6, SSP5-8.5 was described as "the high end of the range of future pathways in the IAM literature" (O'Neill et al., 2016), with a similar end-of-century forcing level as RCP8.5 but with a larger role for methane relative to CO₂. Current discussions for the next generation of scenarios for CMIP7 (van Vuuren et al., 2025) acknowledge that "the plausibility of the CMIP6 high emission levels (quantified by SSP5-8.5) has been questioned" — and they therefore plan to use a high emissions scenario which is "expected to result in forcings below SSP5-8.5" — but at the same time these discussions highlight why high-end scenarios remain a necessary part of a wider set of plausible futures: because even at lower forcings they "explore the risk of reaching possible tipping points ... and how large might the climate change risks be to which society may have to adapt." Thus have the CMIP and IPCC processes responded to changing consensus on the upper plausible bound of future climate change, which itself evolves with changing assessments of energy systems and global socioeconomic conditions.

The claim that "IPCC emission projections have tended to overstate actual subsequent emissions" [page 15 of the CWG] misrepresents the range of emissions scenarios used in the ScenarioMIP process which informed IPCC-AR6. Global emissions continue to grow (Forster et al., 2025; Global Carbon Project, 2024), even if the rate of increase has slowed recently. For the CMIP6 scenarios (O'Neill et al., 2016), current CO₂ emissions remain approximately in line with SSP2-4.5 and SSP4-6.0 (scenarios which do not diverge until the 2030s, see Figure 3). There were

two widely used scenarios significantly above current 2024 levels (SSP5-85 and SSP3-70), and two widely-used scenarios significantly below current CO2 emissions levels (SSP1-19 and SSP1-26). As such, observed emissions are well centered in the ScenarioMIP CMIP6 distribution.

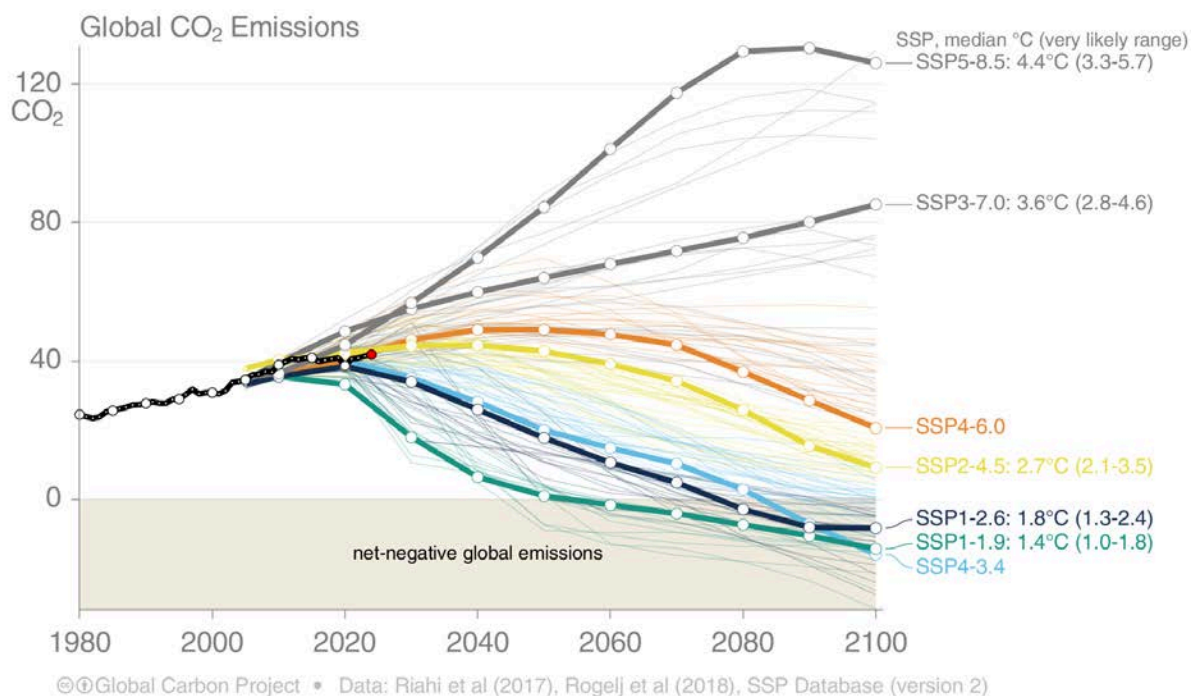


Figure 3: observed carbon dioxide emissions (Global Carbon Project, 2024), black line with 2024 emissions shown as the red filled circle, in the context of CMIP6 scenarioMIP scenarios (O'Neill et al., 2016). Figure prepared as supporting material for the 2024 Global carbon project (globalcarbonproject.org, 2025).

Figure 3, above, differs notably from Figure 3.2.2 in the DOE report. Figure 3.2.2 shows only fossil CO2 emissions and excludes land use, but it is inaccurately characterized in the DOE report as “total global observed CO2 emissions” [figure is on **page 17 of the CWG**, and the inaccurate reference is in the text on **page 16**]. Both land use and fossil CO2 emissions are important in determining the magnitude of future warming. Furthermore, agreement or disagreement between scenarios and observed emissions over the past decade is a limited constraint on the evolution of future emissions over the remainder of the century (Hausfather and Peters, 2020a, b), which depends on both technological costs and policy decisions.

Similarly, the DOE report’s Figure 3.2.1 is copied from Figure S4 in (Hausfather et al., 2020) and purports to show that “observed atmospheric CO2 concentrations tracked the low end of the SRES range and also of subsequent IPCC scenario ranges”. However, **the figure does not show what is being claimed in the DOE report.** Figure 3.2.1 (S4 in (Hausfather et al., 2020)) includes future

CO₂ concentrations projected by 17 climate models published between 1970 and 2001. Only one of the lines – the one in red representing the A2 scenario in the IPCC TAR report – represents a SRES scenario, and it is broadly consistent with observed concentrations in the years after it was published. Earlier climate models that tended to overstate future CO₂ concentrations, but this overstatement was counterbalanced by a lack of non-CO₂ GHGs (e.g. CH₄, N₂O, halocarbons), such that the increase in total forcing in early models is generally lower than in observations (Figure 1 in (Hausfather et al., 2020)).

With respect to total CO₂ emissions (including both best estimates of land use emissions and fossil emissions - as shown in Figure 4a): through 2015, CO₂ emissions were on the high end of the range of SRES scenarios, but over the past decade they have moved toward the middle of the range as emissions have plateaued. In 2024, total CO₂ emissions remained below those of the original RCP8.5, but above RCP4.5 and RCP6.0. Fossil-only CO₂ emissions approximately track RCP4.5 (Figure 5b). In terms of SRES scenarios, fossil emissions remain above B1, B2, and A1T but below A1F1, A2, and A1B.

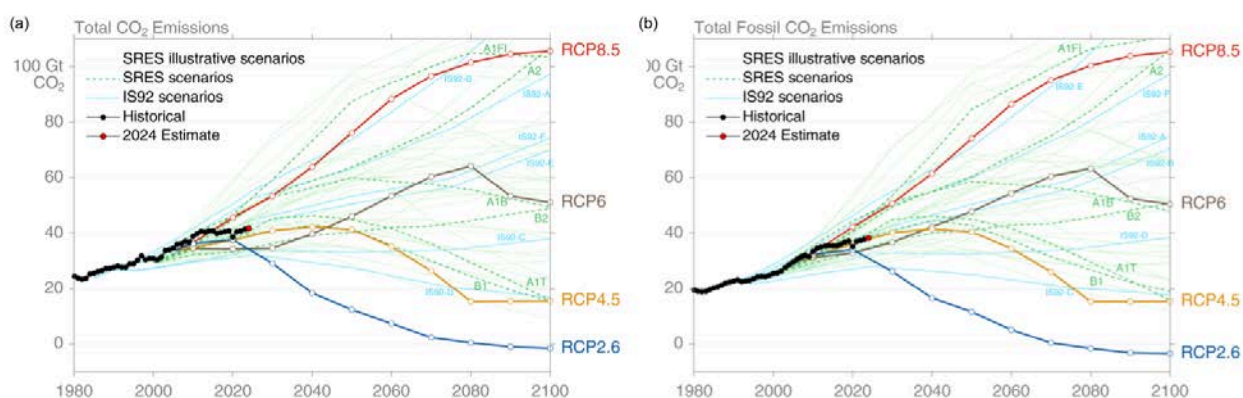


Figure 4: (a) Fossil fuel only and (b) total (fossil+land use) CO₂ emissions in old scenarios (IS92, SRES, and RCPs) compared to observations, Updated from (Peters et al., 2013) with recent data from (Global Carbon Project, 2024) . Figure via Robbie Andrew and Glen Peters.

Comment 4: On the Carbon Cycle

Reference in CWG Report: Page 11 (Summary Statement); pp. 17-19 (Detailed Argument).

Comment Type: Technical. This concerns the flawed and incomplete presentation of carbon-sink science.

Original text/summary statement from CWG: *“Carbon cycle models connect annual emissions to growth in the atmospheric CO₂ stock. While models disagree over the rate of land and ocean CO₂ uptake, all agree that it has been increasing since 1959.”*

Comment:

This statement, and other similar statements in the report misleadingly downplay the magnitude of annual human-induced carbon emissions to the atmosphere by comparing them to the magnitude of natural exchanges with the ocean and land. Human emissions are quoted as being “only about 5 percent of the annual exchange with the atmosphere” [quote from **page 18 of the CWG**].

However, **this line of argumentation is entirely irrelevant to the long-term change in atmospheric carbon concentrations**, which is the salient quantity with regard to climate change. Natural exchanges are broadly in balance on an annual timescale (or multi-annual in the presence of inter-annual variability), meaning that they absorb the same amount as they emit, whereas human emissions knock the system out-of-balance. While imbalances can emerge in the natural exchanges (indeed, such imbalances in the ocean are thought to be the driver of ice age CO₂ changes (Gottschalk et al., 2016)), there is no evidence that any such imbalance is playing a substantive or even contributory role in the present long term rise in atmospheric CO₂ (Canadell et al., 2023; Global Carbon Project, 2024; Graven et al., 2017; Keeling et al., 2017). The distinction between the role of annual exchanges in the natural sinks and the long-term effects of human-induced emissions is most clearly seen by looking at the historical trend in atmospheric CO₂, recorded at the Mauna Loa station (<https://gml.noaa.gov/ccgg/trends/> - Figure 5), where it is evident not only that CO₂ concentrations are increasing, but also that the amount of carbon added to the atmosphere each year has also increased over recent decades, with the rate of increase of atmospheric CO₂ having risen noticeably from ~1.5ppm/yr from 1975-1999 to ~2.3ppm/yr from 2000-2024 (<https://gml.noaa.gov/ccgg/trends/gr.html> - Figure 5 (NOAA Global Monitoring Laboratory 2024)). This highly significant and accelerating trend is misrepresented in the DOE report's Figure 3.1.3 [**page 14 of the CWG**], which uses a limited timeframe and an inappropriate y-axis scale to visually downplay the clear increase in concentrations.

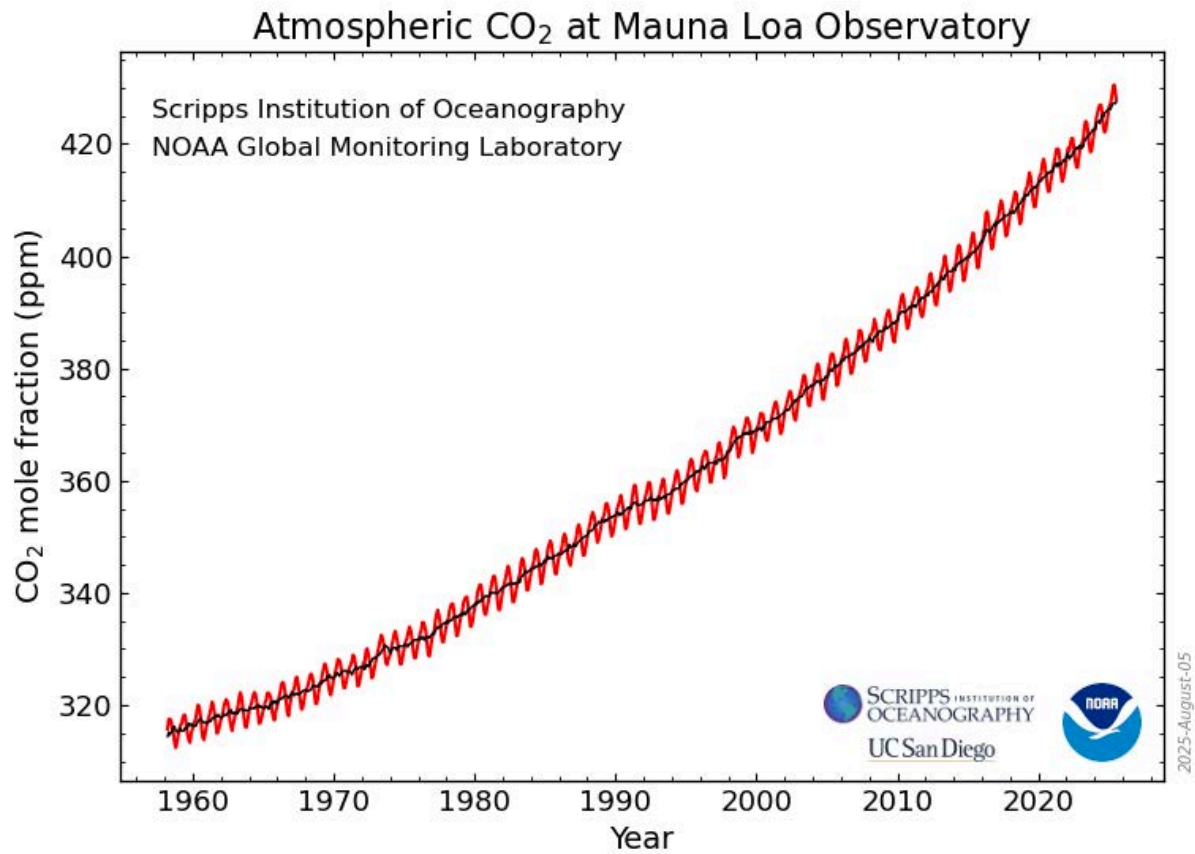


Figure 5: from (NOAA Global Monitoring Laboratory, 2024), red line shows the monthly mean measured CO₂ concentration at the Mauna Loa observatory in Hawaii, USA. The black line removes the seasonal cycle from the signal.

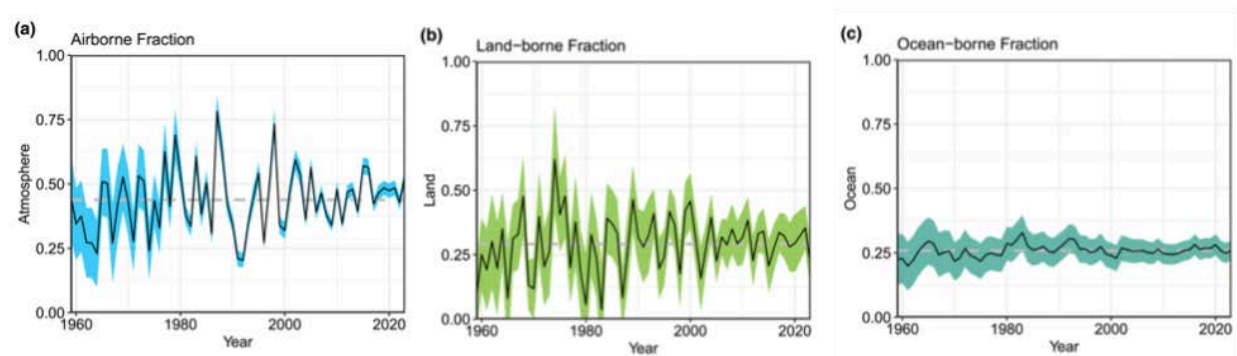


Figure 6 (from (Global Carbon Project, 2024)), showing the best-estimate of fraction of atmospheric CO₂ emissions from fossil and land use sources which are accumulated in the atmosphere (a), land (b) and ocean (c). Black lines represent the central estimate, and the coloured shading represents the uncertainty. The dashed grey lines represent the long-term

average of the airborne (44 %), land-borne (30 %), and ocean-borne (25 %) fractions during 1960–2023.

The effects of annual natural exchange are evident as the cycles that occur around the long term increasing trend. The impacts of human emission on atmospheric carbon – in spite of large annual exchange with the ocean and land — are entirely unambiguous (Forster et al., 2025; Global Carbon Project, 2024; Masson-Delmotte et al., 2023), a finding supported by the evidence of isotopic ratios of carbon in the atmosphere which differ between living and fossil carbon sources (Graven, 2015). Fossil fuels are derived from ancient plant matter, which is naturally depleted in the Carbon-13 isotope and contains no radioactive Carbon-14, which is otherwise continuously formed in the upper atmosphere by cosmic rays ([Lal and Peters 1967](#)). Consequently, the observed decrease in the atmospheric ratio of both Carbon-13 and Carbon-14 serves as a definitive fingerprint of carbon from fossil fuel combustion ([Graven et al. 2017](#)). Debate on this point has been settled for decades (Lynas et al., 2021)

The report emphasizes that the ocean and land sinks have taken up around 50% of historical carbon emissions [page 14 and page 18 of the CWG], and that this fraction has remained approximately constant over time. There is little debate that while atmospheric CO₂ levels increase, the planet's land and oceans respond by absorbing a portion of this CO₂. Historical allocation of carbon emissions to the land (30 %), oceans (25 %) and atmosphere (44 %) has remained remarkably constant (Crisp et al., 2022; Global Carbon Project, 2024). The authors leverage this fact of historically constant airborne fraction to point out therefore that the land and ocean sinks must have increased in absolute magnitude. Therefore, they implicitly suggest, the natural sinks can, have, and will mitigate against rising emissions. This logic is fundamentally flawed and the framing critically misleading for several reasons:

1. **The quantity relevant to climate change via the concentration of atmospheric CO₂ is the fraction of emissions taken up by the land and ocean, not the absolute magnitude of these sinks**, which the report tries to focus on. Consider the case of the industrial period: emissions increase and the fraction taken up by the land and ocean remains the same (i.e. 50%). While the absolute uptake by land and ocean has increased, so too has the amount remaining in the atmosphere (50% of the increased emissions). For the natural sinks to provide a mitigating effect to increasing emissions, their fractional uptake, rather than just their absolute magnitude, would need to increase to maintain atmospheric CO₂ at present levels.
2. The broad mechanisms for historically-increasing uptake of CO₂ by land and ocean are well established to be driven by the increasing atmospheric CO₂ — as the DOE report authors in fact note in the 3rd full paragraph on p18. Crucially, therefore, these **natural sinks will only continue to increase if atmospheric CO₂ itself continues to increase** (Arora et al., 2020; Global Carbon Project, 2024; Keenan and Williams, 2018; MacDougall et al., 2020). As a result, these sinks can never exceed emissions — and atmospheric CO₂ will continue to increase — until emissions are curtailed and atmospheric levels start to reduce. (The precise evolution of land and ocean carbon sinks after peak emissions is an area of widespread research (MacDougall et al., 2020; Sanderson et al., 2024).)
3. **The historical evolution of the land and ocean carbon sinks (which the report exclusively focuses on) is well known to be a poor predictor of future changes.** In the

ocean, the CO₂ uptake capacity decreases with every unit of carbon absorbed historically – a well-established consequence of ocean carbonate chemistry known as “buffering” (Bates et al., 2014). Future projections of the ocean carbon cycle disagree only about how rapidly this slowdown will progress, since it depends on the rates of ocean circulations and changes therein (Arora et al., 2020). Rising sea-surface temperatures also reduce the solubility of CO₂, directly impeding the ocean's uptake capacity (Masson-Delmotte et al., 2023), which in simulations of medium and high emissions scenarios impacts fractional ocean sink uptake (Arora et al., 2020). Future circulation changes such as a weakening Atlantic Meridional Overturning Circulation could also act to further decrease fractional ocean sinks (Schaumann and Alastrué de Asenjo, 2025), with some evidence of an observed weakening of sink strength in recent assessments of oceanic carbon trends (Müller et al., 2023). For the land, while elevated CO₂ can enhance plant growth, this effect is significantly constrained by nutrient limitations in the soil (Fleischer and Terrer, 2022) and negative effects of temperature on plant growth (Fernández-Martínez et al., 2019). Moreover, suppressed land carbon uptake was linked to the record atmospheric CO₂ growth in 2023-2024 (Global Carbon Project, 2024; Gui et al., 2024). This growth is being compounded by the thawing of carbon-rich permafrost, now considered a definite amplifying feedback to global warming (Canadell et al., 2023; Smith et al., 2022). Although the global forest sink has appeared stable in absolute terms, there have been regional shifts in uptake and much of this benefit has been offset by deforestation (Pan et al., 2024). In short, established biogeochemical principles and emerging observations for both land and ocean sinks point toward a future of progressively diminishing efficiency in absorbing anthropogenic CO₂, and an increase in airborne fraction as climate change increases (Canadell et al., 2023; Crisp et al., 2022).

In summary, the DOE report critically misrepresents the scientific understanding of land and ocean carbon sinks, using them to foster a misleading sense of complacency regarding human-induced climate change. It conflates the absolute magnitude of carbon uptake with the crucial fractional uptake, thereby ignoring the fact that natural sinks must increase their fractional uptake to mitigate rising emissions. Furthermore, the report largely omits extensive literature on the future behavior and potential degradation of these sinks. It fails to acknowledge that these natural sinks are primarily driven by increasing atmospheric CO₂, and that their capacity to absorb carbon is not limitless, particularly for the ocean due to buffering and warming, and for land due to nutrient limitations, negative temperature effects, and permafrost thawing. By focusing exclusively on historical trends and neglecting the complexities and vulnerabilities of future sink behavior, the DOE report presents an incomplete and skewed picture that downplays the urgency of emission reductions.

Comment 5: On Urbanization and Temperature Records

Reference in CWG Report: Page 11 (Summary Statement); pp. 20-21 (Detailed Argument).

Comment Type: Technical. This addresses the report's inaccurate assessment of the Urban Heat Island (UHI) effect on global data.

Original Text/summary statement from CWG Report: "There is evidence that urbanization biases in the land warming record have not been completely removed from climate data sets".

The inclusion of data from urban and suburban weather stations does not appreciably change the large-scale averages in global temperature datasets like (Rohde et al., 2013). While the Urban Heat Island (UHI) effect is a real and well-documented local phenomenon, comprehensive studies have repeatedly shown that it has a minimal impact on the calculated warming trend for continents and the planet as a whole (Hausfather et al., 2013). This conclusion is supported by two primary lines of evidence. First, the standard scientific practice of **homogenization** effectively detects and removes non-climatic biases from the raw data, including the artificial warming signals from urbanizing stations (Hausfather et al., 2013). This finding holds even when only rural stations are used for breakpoint detection and correction in the homogenization process to avoid any risk of aliasing in a UHI signal (Ibid).

Second, results from these adjusted datasets are independently validated by **rural-only networks** (like the U.S. Climate Reference Network), which show nearly identical rates of warming (e.g., (Hausfather et al., 2016; Vose et al., 2014). This finding is reflected by the IPCC Regional fact sheet on Urban Areas, which states that urban heat effects have “a negligible impact on global annual mean surface air warming (very high confidence)” (Regional fact sheet - Urban Areas, 2025). Additionally, data from AIRS satellite measurements (Susskind et al., 2019) show comparable rates of warming as the full land station network during the period of overlap, suggesting minimal UHI biases in recent decades.

Modern reanalysis products like ERA5 and JRA-3Q also provide a constraint on the potential magnitude of UHI biases given the large amount of additional data they assimilate from satellites, planes, radiosondes. If urban warming were being incorrectly spread across large areas by surface station-based land temperature reconstructions, using a much larger volume of more spatially complete data would tend to catch this given resulting inconsistencies between variables over space and time (e.g. temperature and pressure). However, reanalysis products largely agree with surface temperature records in terms of global and regional land surface temperature trends.

Finally, the DOE report fails to place its discussion of potential UHI biases in the broader global context. This spatial structure of warming shows coherent warming patterns not confined to urbanized areas, with the strongest warming in remote high-latitude regions – broadly in-line with modeled expectations of warming patterns (Hahn et al., 2021). The world is also >70% oceans, so even the presence of a significant (>10%) bias in land temperatures, if it existed, would have a much smaller effect on resulting global surface temperatures.

Recommendations for revision

Based on a critical review of Section 3, "Human Influences on the Climate," of the DOE report "A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate," we recommend the following revisions to correct factual errors, address selective evidence presentation, and rectify issues with reference interpretation:

1. Correction of Misrepresentation of IPCC Scenarios

- *Revise the portrayal of IPCC scenarios:* The report should accurately reflect that IPCC scenarios are not predictions but exploratory "what-if" tools designed for risk assessment under deep uncertainty, as consistently stated by the IPCC.
- *Acknowledge the evolving nature of high-end scenarios:* Clearly state that the assessment of upper plausible bounds of future emissions evolves with changing technological, economic, and geopolitical factors, and that high-end scenarios remain necessary for exploring upper-bounds on risks and tipping points.
- *Correct the claim about overstated emissions projections:* The report should acknowledge that observed CO₂ emissions, rather than solely tracking the low end of projections, are well-centered within the CMIP6 ScenarioMIP distribution.

2. Accurate Representation of Human Influence on Climate

- *Clarify the dominant role of human activities:* The report must unequivocally state that human activities, particularly greenhouse gas emissions, are not merely an additive factor to natural variability, but the primary and dominant driver of observed global warming since the industrial era. This statement aligns with IPCC AR6 and NCA5 conclusions.
- *Incorporate comprehensive attribution evidence:* Include the robust, multi-faceted evidence for human-caused warming, such as energy budget analyses, climate model simulations, and physical "fingerprints" of warming (e.g., cooling stratosphere, carbon isotopic ratios), which consistently show natural drivers having a negligible or even slightly cooling effect over the long term.

3. Comprehensive Discussion of Carbon Cycle and Natural Sinks

- *Distinguish between absolute and fractional uptake of carbon sinks:* The report should emphasize that for climate change, it is the *fraction* of human emissions taken up by land and ocean sinks that is crucial, not just their absolute magnitude - given that it is the fraction of future emissions which remain resident in the atmosphere which is the relevant measure of the degree to which sinks will counter emissions. The annual increase in CO₂ concentrations is about half of the CO₂ emitted because land and ocean processes currently absorb "excess" CO₂ at a rate approximately 50 percent of human emissions, but there remain risks that these sinks could weaken in the future.
- *Address the future behavior and limitations of natural sinks:* Include the extensive literature on the potential degradation and limitations of land and ocean carbon sinks due to factors like ocean buffering and warming, nutrient limitations in land ecosystems, negative temperature effects on plant growth, and permafrost thawing. The report's exclusive focus on historical trends is incomplete and misleading.
- *Correct the downplaying of human emissions:* Remove the misleading comparison of human emissions to natural exchanges that states human emissions are "only about 5 percent of the annual exchange with the atmosphere." Instead, clarify that human emissions disrupt the natural balance of the carbon cycle, leading to the long-term increase in atmospheric CO₂ concentrations.

- *Provide accurate context for ocean biological processes:* While the uncertainty of ocean biological CO₂ uptake is noted, the report should clarify that, unlike on land, there is no clear mechanistic reason to expect an increase in ocean biology due to CO₂ fertilization.

4. Corrected Assessment of Urban Heat Island (UHI) Effect

- *Acknowledge minimal UHI impact on global warming trends:* The report should reflect the scientific consensus that while the UHI effect is a local phenomenon, it has a minimal impact on large-scale global temperature averages and calculated warming trends.
- *Highlight effective data homogenization and rural-only validation:* Emphasize that standard homogenization practices effectively remove non-climatic biases, including UHI signals, and that results are validated by rural-only networks and satellite measurements showing consistent warming rates.
- *Consider the global context of warming:* Reinforce that warming patterns are coherent globally, not confined to urbanized areas, with strongest warming in remote high-latitude regions, and that oceans cover over 70% of the Earth's surface, further minimizing any potential land-based UHI bias on global temperatures.

5. Inclusion of a More Complete and Balanced Literature Review

- *Avoid cherry-picking non-consensus views:* The report should avoid selectively highlighting studies that present non-consensus views (e.g., on solar influence or UHI bias) as representative of scientific debate when the overwhelming weight of independent lines of evidence point to a clear consensus.
- *Present a balanced view of critiques and responses:* When presenting critiques of scientific findings, the report should also include the responses and counter-arguments from the broader scientific community, such as the critiques of statistical methods used in certain studies (e.g., (Richardson and Benestad, 2022) regarding solar influence).

6. Corrected Presentation and Contextualization of Atmospheric CO₂ Concentrations

We suggest a revision of the CWG figure 3.1.2 as follows:

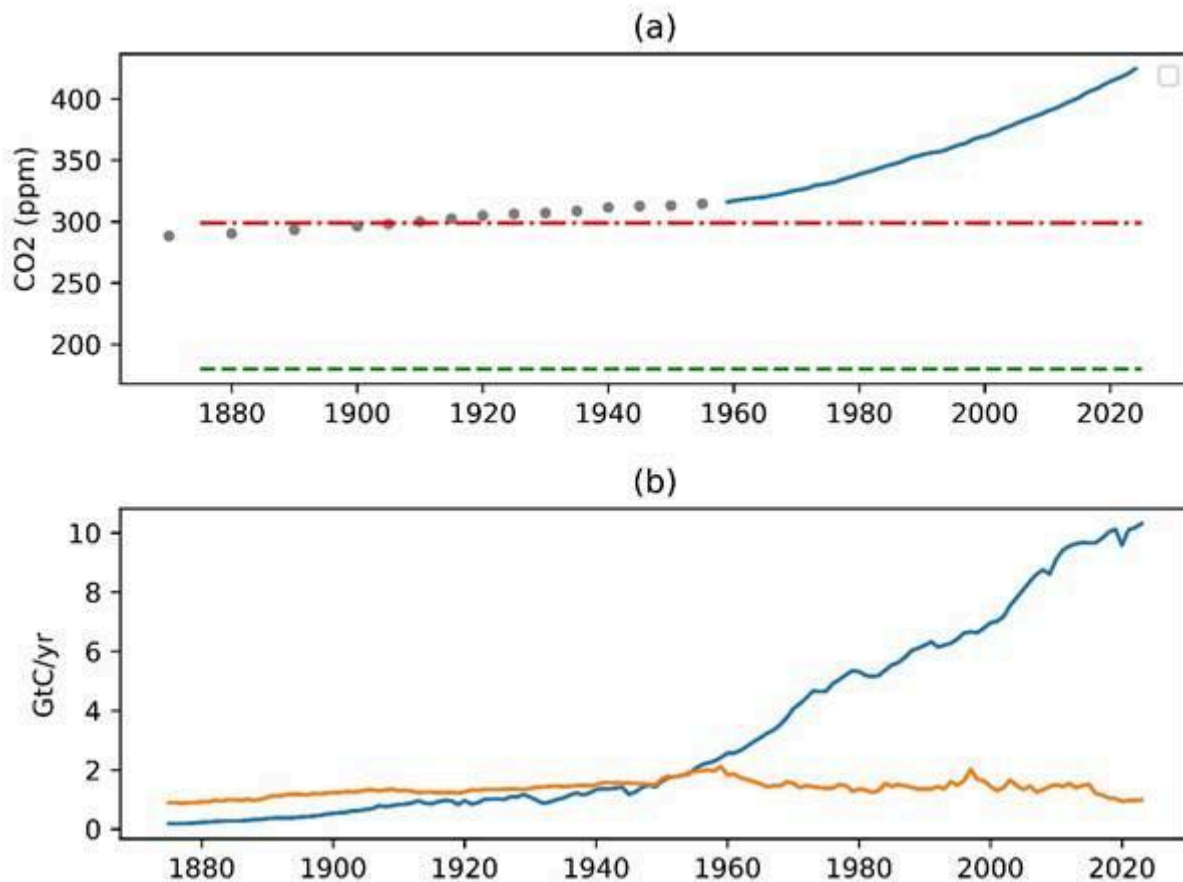


Figure 3.1.2 (suggested revision). (a) Yearly Average CO₂ concentrations as measured at Mauna Loa (1959-2024; blue line)(Trends in CO₂ - NOAA Global Monitoring Laboratory, 2025), and as reported by the IPCC (1870-1955; gray dots)(Anon, 2023). The green dashed line is the minimum CO₂ level during recent glaciations (180 ppm). The red dot-dashed line is the maximum interglacial level (299 ppm). (b) Annual carbon emissions from fossil emissions excluding carbonation (blue line) and from land-use change (orange line), as reported by the (Global Carbon Project, 2024). All values are in billions of tons of carbon per year (GtC/Yr); multiply by 3.664 for values in billions of tons of CO₂.

- **Address misleading visual representation of CO₂ data:** Revise Figure 3.1.3 in the DOE report to:
 - Include earlier CO₂ data (e.g., from the IPCC) to illustrate the dramatic change in growth rate beginning in the 1950s.
 - Adjust the y-axis scale to appropriately display the CO₂ concentration data, avoiding the visual impact of making the curve appear shallower.
- **Remove irrelevant C3 and C4 plant thresholds:** Delete the discussion of C3 and C4 plant thresholds as they are irrelevant to the current and projected atmospheric CO₂ concentrations.

- **Incorporate historical CO₂ context:** Plot the interglacial maximum CO₂ concentration alongside the glacial minimum to clearly show that current concentrations are far outside the range seen in the past 805,000 years and that the increase in the past 7 decades is comparable to the increase between glacial maxima and minima.
- **Clarify the shift in dominant emission sources:** Note that fossil fuel emissions became the overwhelmingly dominant source of CO₂ additions to the atmosphere from the 1950s onward, exceeding land-use change emissions.

Suggested update to summary statements

Given the above we suggest the following update to the Chapter 3 summary statements:

- **On the Cause of Recent Warming:** Human activities are the dominant cause of the observed global warming since the industrial era. While the climate is naturally variable on all timescales, this variability has had a negligible contribution to the long-term warming trend compared to the influence of anthropogenic greenhouse gas emissions.
- **On the Role of Natural Influences:** Major scientific assessments, including the IPCC AR6 and NCA5, conclude that the contribution of solar activity to recent global warming is negligible. While a wide range of literature is assessed, the overwhelming evidence from multiple independent lines of analysis indicates that natural drivers, including the sun, cannot account for the observed warming.
- **On the Use of Climate Scenarios:** IPCC climate scenarios are not predictions but are exploratory "what-if" tools designed for risk assessment under deep uncertainty. Observed global CO₂ emissions are currently tracking within the middle of the range of the most recent CMIP6 scenarios. While the use of the extreme scenario RCP8.5 as a 'business-as-usual' projection has been characterized as misleading, high-end scenarios remain necessary tools for understanding potential high-risk climate outcomes and tipping points.
- **On the Carbon Cycle:** Land and ocean carbon sinks have increased their absolute uptake of CO₂ in response to rising anthropogenic emissions, absorbing a relatively constant fraction of about 50% of emissions to date. However, this historical trend is not a reliable predictor of future behavior, as the capacity of these sinks is projected to be limited by factors such as ocean carbonate chemistry (buffering), warming ocean waters, nutrient constraints and warming effects on land carbon uptake. Focusing only on increasing absolute uptake fosters a misleading sense of security.
- **On Urbanization and Temperature Records:** The scientific consensus, reflected in IPCC reports, is that the Urban Heat Island (UHI) effect has a minimal to negligible impact on calculated global and continental-scale warming trends. Standard data homogenization procedures effectively detect and remove non-climatic biases from the temperature record, and these corrected datasets are independently validated by rural-only networks and satellite measurements.

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Section 3.1.1: Historical Radiative Forcing

Dr. Theodosios Chatzistergos and Dr. Ted Amdur

1. **Suggestion of bias by IPCC by stating that it prefers TSI series that imply minimal solar change since preindustrial times**
2. **Suggestion that existing plausible TSI reconstructions cover the range of no to most of 20th century warming being attributable to the Sun.**
3. **Exaggeration of ACRIM-gap issue**

To correct these technical flaws, the following changes must be made in the DOE CWG report document:

- 1) Update the text to correctly cite the relevant scientific literature and make sure to mention that it is predominantly showing that solar influence on Earth's climate has a rather small net effect between Maunder minimum and present/second half of 20th century.
- 2) Remove erroneous statements about the IPCC reports.
- 3) Either remove the discussion about ACRIM-gap or present it in an unbiased way, highlighting that current understanding through various independent studies disfavors the hypothesised TSI increase during the ACRIM-gap.

1) **IPCC reasoning for solar forcing datasets**

Page: 12

Comment type: Technical

Comment: the DOE report asserts that IPCC chose the TSI forcing datasets based on their preference for series that exhibit small variations. This is erroneous and misleading. The selection of total solar irradiance (TSI) reconstructions for use in climate modeling, such as those adopted in CMIP6 and the IPCC's Sixth Assessment Report (AR6), is not based on the magnitude of variability they imply, but rather on the scientific robustness and performance of the models themselves (Matthes et al. 2017). For CMIP6, the two TSI reconstructions used were **SATIRE** (Yeo et al. 2014, Wu et al. 2018) and **NRLTSI** (now referred to as NNLSI) (Coddington et al. 2016). These were chosen because they represent the most advanced models available at the time, SATIRE being a semi-empirical physics-based model, while NRLTSI a proxy (regression) model. Both models show excellent agreement with direct satellite observations of TSI and have undergone extensive scrutiny and validation (Coddington et al. 2019; Chatzistergos et al. 2025; Wu et al. 2018).

2) **Current state in long-term TSI reconstructions**

Pages: 12-13

Comment type: Technical

Comment: This DoE relies on a publication by Connolly et al. 2021 to argue for a huge uncertainty in the secular trend in TSI reconstructions, thus suggesting that depending on the choice of TSI series one can attribute no or most of the 20th century warming. Although there is indeed uncertainty in the secular trend of irradiance variations, Connolly et al. 2021 and as a consequence the DoE report exaggerate this by cherry picking outdated and implausible TSI series and presenting them as equally probable to others.

To do this, the DoE report ignores the vast majority of scientific literature on the topic of solar variability and irradiance measurements and modeling. All recent and comprehensive review papers about solar irradiance modelling are ignored (e.g. Solanki et al. 2013; Chatzistergos et al. 2023).

In particular, Chatzistergos et al. 2023, collected most (if not all) available reconstructions of total solar irradiance (TSI) that cover the period 1700-1986 grouping different versions of individual models together. They found 24 groups of models, out of which 21 suggest a rather small secular trend (here defined as difference between activity minima in 1986 and 1700) that is between -0.09 and 2.2 Wm^{-2} . Only 3 groups of models were found to exhibit a high secular trend (Hoyt and Schatten 1993; Egorova et al. 2018; Fligge and Solanki 2000). As noted in Chatzistergos et al. 2023, the study by Fligge and Solanki 2000 is “considered replaced by the newer SATIRE-family models”.

The model by Hoyt and Schatten 1993 has been thoroughly discredited (Chatzistergos 2024). It introduced arbitrary adjustments and even fabricated data, some of which appear to have been copied from another solar index. The Egorova et al. 2018 model relies heavily on assumptions about the Sun’s quietest possible state, a critical and uncertain input. This approach has been strongly criticized by Yeo et al. (2020), who demonstrated that the long-term TSI variability in the Egorova et al. 2018 model is exaggerated. The Yeo et al. 2020 study established a robust constraint on the dimmest state of the Sun, the lowest expected value in TSI, to be $2 \pm 0.7 \text{ W/m}^2$ below the value of the 2019 minimum, thus excluding the Egorova et al. 2018 reconstruction. Overall, despite the uncertainty in estimating the secular trend in TSI variations, current models suggest a relatively weak secular trend, and all high variability models have been criticized or even rendered invalid (in the case of Hoyt and Schatten 1993). While old versions of models that were at some point suggesting high secular trends, have been typically revised and now exhibit low secular trends.

Chatzistergos et al. 2023 also states: “often older versions are used in the literature ignoring the fact that newer versions, overriding the earlier ones, are available. We caution against using outdated reconstructions.”

This comment addresses the main issue with the presentation of TSI reconstructions by Connolly et al. 2021. In particular, Connolly et al. 2021 cherry-picked a set of 16 TSI series, deliberately balancing the sample to include eight with low long-term variability and eight with high variability. To achieve this equal division, they included outdated or superseded versions of

some models, while they ignored many low variability TSI reconstructions. Connolly et al. 2021 did not clarify how the division between high and low variability series was done, but all high variability series they used lie outside the constraint imposed by Yeo et al. (2020), so it is safe to consider them here as TSI series that exhibit variations exceeding $2 \pm 0.7 \text{ W/m}^2$ below the value of the 2019 minimum.

The high variability group in Connolly et al. 2021 includes:

- **Hoyt and Schatten (1993)** has been thoroughly discredited (Chatzistergos 2024). It introduced arbitrary adjustments and even fabricated data, some of which appear to have been copied from another solar index.
- **Lean et al. (1995)** is an early and now outdated version of the NRL model. It has long been superseded by newer versions, latest by NNL.
- **Bard et al. (2000)** reconstructed TSI by applying a simple linear scaling to the production rates of cosmogenic isotopes (e.g., ^{10}Be), without accounting for nonlinear effects such as geomagnetic modulation (Usoskin 2023). More recent and physically realistic models, such as **SATIRE-M** (Wu et al. 2018), explicitly incorporate this and indicate substantially lower long-term TSI variability. Furthermore, Delaygue and Bard (2011) revised the original Bard et al. (2000) reconstruction downward, but Connolly et al. (2021) ignored this update.
- **Shapiro et al. (2011)** an older version of Egorova et al. 2018
- **Egorova et al. (2018)** Connolly et al. 2021 included this model four times (five considering the Shapiro et al. 2011 too) as distinct reconstructions. This model is criticized by (Yeo et al. 2020)

An additional important point is that in all these eight high variability TSI series used by Connolly et al. (2021), the long-term TSI variability was not derived from observational constraints but was instead imposed as a model assumption. Modern updates of the NRL model (Coddington et al. 2019; Lean 2018) and Hoyt and Schatten 1993 (Chatzistergos 2024), have shown that high the variability that was imposed in the earlier versions is inconsistent with direct TSI measurements and have therefore been revised to show lower variability.

Thus, it is misleading based on the above to consider these high variability TSI reconstructions equally probable as the low variability ones. Furthermore, Connolly et al. (2023), although not cited in the DoE report, extended the analysis by Connolly et al. (2021) to include 27 TSI series, but the same criticism stands. They again used multiple outdated and overwritten versions of models, while the reconstructions by Hoyt and Schatten (1993) and Bard et al. (2000) are the ones resulting in their highest attribution of temperature change to the Sun, both TSI series discontinued and shown to have methodological issues. Richardson and Benestad (2022) has also criticized the methodology used by Connolly et al. (2021) to attribute temperature changes to TSI.

Overall, while uncertainty remains regarding the precise magnitude of long-term solar irradiance trends, Connolly et al. 2021 significantly overstates the Sun's role in recent climate change by

selectively including outdated, superseded, and implausible TSI reconstructions that are inconsistent with modern observational and theoretical understanding.

3) ACRIM-gap

Page: 13

Comment type: Technical

Comment: The DoE report exaggerates the significance of the ACRIM-gap. The delay in the launch of ACRIM2 led to the necessity of using data from Nimbus7-ERB and ERBE-ERB. Nimbus7-ERB is the oldest space-based TSI measuring instrument we have, while ERBE-ERB has lower quality and took observations more sporadically than Nimbus7-ERB. The whole ACRIM-gap issue originates in unaccounted sensitivity changes in either or both of those missions. Nimbus7-ERB suggested a slight increase in TSI between 1990-1992, while ERBE-ERB did not.

While a subset of literature has argued for decades that, through a certain interpretation of the ACRIM-gap, solar irradiance changes since 1978 are unknown or upwards, we have independently led two scientific studies that demonstrate a common understanding of the trends in solar irradiance since 1978, regardless of one's chosen interpretation of the ACRIM-gap.

First, Amdur and Huybers (2023), followed by Amdur and Huybers (2025), developed an independent statistical analysis using a sophisticated Bayesian approach inspired by the time series econometrics literature. In these studies, with clearly defined priors that make no *a priori* assumptions regarding the relative merits of using a given satellite or solar proxy in filling the ACRIM-gap, they find that the best estimate of Total Solar Irradiance (TSI) using almost all available observational satellite data supports a downward trend in TSI since 1978, in line with most reconstructions of irradiance.

Second, Chatzistergos et al. (2025) performed irradiance reconstruction with the physics-based semi-empirical model SATIRE-S using datasets that span the entire ACRIM-gap period and extend beyond it. This modeling approach returns long-term TSI trends that are independent of direct TSI measurements, although some uncertainty remains due to the quality of the input data. By applying the model separately to two independent datasets, Mt. Wilson magnetograms and reconstructed unsigned magnetograms from Meudon Ca II K observations, Chatzistergos et al. 2025 demonstrated that both reconstructions contradict the TSI increase suggested by some during the ACRIM-gap, providing independent evidence against that upward trend.

Thus, while the issues leading to the ACRIM-gap contribute to the uncertainty in the long-term trends in direct TSI measurements, both statistical and physics-based reconstructions relying upon independent data find a common resolution to the ACRIM-gap, and it is important to note that these findings are consistent with existing TSI composites that do not exhibit substantial disagreement (Kopp 2025). In particular, Chatzistergos et al. (2023) in their Table 1 lists the trend between activity minima of cycle 25 (2019) and 22 (1986) and shows that it is rather small

ranging between $-7.6 \text{ mW m}^{-2} \text{ y}^{-1}$ (Montillet et al. 2022) and $1.8 \text{ mW m}^{-2} \text{ y}^{-1}$ (Scafetta 2023) (the latter is an informal update of ACRIM TSI composite). Most recently, Amdur and Huybers (2025) found a trend of $-5 \text{ mW m}^{-2} \text{ y}^{-1}$ over this period.

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Section 3.2.1: Emissions scenarios

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Reference in CWG Report: pp. 15

Comment Type: Technical. This addresses the report's misinterpretation of the use of climate scenarios.

Original Text/summary statement from CWG Report: "Although the IPCC does not claim its emission scenarios are forecasts, they are often treated as such".

Comment:

The text suggests that the IPCC is unclear about the meaning of emission scenarios, which is not the case. Each Working Group report in AR6 explicitly states how emission scenarios are to be interpreted and used. For example, here is the statement of the emissions scenarios in BOX SPM .1 of AR6 Synthesis Report (IPCC, 2023): "Modelled scenarios and pathways are used to explore future emissions, climate change, related impacts and risks, and possible mitigation and adaptation strategies and are based on a range of assumptions, including socio-economic variables and mitigation options. These are quantitative projections and are neither predictions nor forecasts. IPCC is neutral with regard to the assumptions underlying the scenarios in the literature assessed in this report, which do not cover all possible futures".

Reference in CWG Report: pp. 16

Comment Type: Technical. This addresses the report's misinterpretation of the development of climate scenarios.

Original Text/summary statement from CWG Report: "The IPCC developed a new set of scenarios for AR6, the "Shared Socioeconomic Pathway" (SSP) scenarios, which have continued the bias shown in the RCP and SRES scenarios".

Comment:

This text is false because the SSP scenarios were developed not by the IPCC but by international science communities. It is important to recognize that the AR6 WGIII (Riahi et al., 2022) assessed a large number of global modelled emissions pathways (about 1202) which were categorised based on their assessed global warming over the 21st century; categories range from pathways that limit warming to 1.5°C with more than 50% likelihood (noted >50% in this report) with no or

limited overshoot (C1) to pathways that exceed 4°C (C8). IPCC AR6 WGI assessed the climate response to selected five illustrative scenarios based on Shared Socio-economic Pathways (SSPs) that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. It is also very important to note that AR6 WGIII Chapter 3.3 comprehensively assessed feasibility of emissions scenarios including SSP5-8.5 and SSP1-1.9. Those assessments in IPCC AR6 reports are not recognized in this report.

IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

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Review of the DOE document titled “A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate”

David Crisp

I am a former Senior Research Scientist at NASA’s Jet Propulsion Laboratory. I led the science teams for NASA’s Orbiting Carbon Observatory missions (OCO-2 and OCO-3), focusing on satellite-based greenhouse gas measurements.

I am the first author of Crisp et al. (2022). The DOE CWG report claims to rely heavily on this review paper to inform its understanding of land-ocean-atmosphere carbon cycling. Regarding this paper, the DOE CWG report states,

The relation between emissions and concentration is determined by the global carbon cycle of land and ocean processes that exchange carbon with the atmosphere. Our understanding of these processes was reviewed by Crisp et al. (2021) [sic].... While land vegetation has been responding positively to more atmospheric CO₂, uptake of extra CO₂ by ocean biological processes remains too uncertain to be measured reliably. Our current understanding of these and many more carbon cycle processes was reviewed by Crisp et al. (2021) [sic].

This is a comment on Section 3.2.2, which explains how the global carbon cycle links fossil fuel emissions to atmospheric CO₂ levels. It describes the major carbon reservoirs and the annual exchange of roughly 200 gigatonnes of carbon between the atmosphere, land, and oceans, noting that human activities add about 10 GtC/year — only ~5 % of that exchange. Historically, land vegetation and oceans have removed about half of these human emissions, with land uptake increasing more than ocean uptake, but model estimates of these fluxes vary widely, introducing uncertainty into projections of future CO₂ concentrations and climate change.

- **Page:** 17
- **Comment Type:** Reference
- **Comment:** 1st paragraph: Our work is cited as “Crisp et al. (2021).” The paper included in their reference list is actually the review paper by Crisp et al. (2022). There is no paper by Crisp et al. (2021) covering this topic to the best of our knowledge.
- **Fix:** Correct this reference.

- **Page:** 17
- **Comment Type:** Technical
- **Comment:** 2nd paragraph: The total mass of carbon in the atmosphere is increasing over time as the carbon dioxide concentration increases. Crisp et al. (2022) quoted a mass of 877

Peta grams of Carbon (Pg C; one Pg C is equivalent to billion tons of carbon (GtC) or 3.67 billion tons of CO₂), which was a good estimate in 2020, when the atmospheric CO₂ dry air mole fraction (a measurement of concentration) was around 412 ppm. Here, their estimate of “about 850 GtC”, was relevant around a decade ago, when the average CO₂ concentration was closer to 400 ppm.

- **Fix:** Correct this error with a more recent value.

- **Page:** 17
- **Comment Type:** Technical
- **Comment:** 2nd paragraph: The quoted gross annual exchange of carbon between land and the atmosphere and between the ocean and the atmosphere are erroneous (and their relative values seemingly reversed). Here, they state that land exchanges 80 Gt C with the atmosphere and the oceans exchange 120 Gt C with the atmosphere. They do not cite specific sources for these numbers and they do not come from Crisp et al. (2022). In Crisp et al. (2022) the values provided for gross carbon flux are 120-175 GtC per year for land-atmosphere and 90 GtC for gross ocean-atmosphere.
- **Fix:** Correct these errors and provide a correct reference.

- **Page:** 17
- **Comment Type:** Technical
- **Comment:** They end this paragraph by noting that the 10.3 GtC emitted by fossil fuel use and cement manufacturing is only about 5% of annual emissions by the land biosphere and oceans. This is a half-truth that fails to recognize that the atmosphere and climate respond to the net emissions and removals of carbon, not the gross fluxes. The land biosphere and ocean both add and remove carbon from the atmosphere whereas fossil fuel use and other human activities only add carbon to the atmosphere. When averaged over the globe and over the year, the land biosphere and ocean remove as much carbon as they emit. The land and ocean also remove over half of the anthropogenic emissions, yielding net emissions that are negative and only about half as large as the positive anthropogenic emissions. In this context, the net anthropogenic emissions are more than twice as large as the net natural CO₂ fluxes (Friedlingstein et al, 2025).
- **Fix:** Change the wording to reflect the above facts, specifically that the net anthropogenic emissions are twice as large as the net natural CO₂ fluxes.

- **Page:** 18
- **Comment Type:** Technical
- **Comment:** 1st paragraph: Here, they recognize that existing observations show that natural processes in the land biosphere and ocean consistently remove about 50% of the

anthropogenic CO₂ emissions. They also note that this ratio has been preserved as the fossil fuel emissions have increased. They attribute the increasing land uptake to the “global greening” phenomena described in Section 2.1 of this work.

However, Section 2.1 fails to recognize that the increasing leaf area index (LAI) does not always indicate increased CO₂ uptake. In particular, as noted in Crisp et al. (2022), many regions of the tropics, where the largest increases in LAI have been seen over the past 50 years, have started to transition from net CO₂ sinks to net sources of CO₂. These changes are due to the impacts of human activities (e.g. deforestation, forest degradation) and climate change (increasing temperature, drought, vapor pressure deficit).

The authors also fail to note that while tropical land is absorbing less CO₂, these losses are being compensated mostly by increased carbon uptake by forests at mid and high latitudes. There, climate change is driving longer, warmer growing seasons, and permafrost melt is allowing trees to grow deeper, more massive root systems that sequester more carbon in the soil. The rapid growth, combined with higher temperatures and more frequent droughts at these latitudes, produce larger and more frequent wildfires, which release CO₂. In summary, while the fraction of the anthropogenic CO₂ that has been absorbed by the land biosphere has remained almost constant in response to increasing atmospheric CO₂ abundances, different parts of the world are responding differently to climate change (Byrne et al., 2020). The focus on “global greening” is a massive oversimplification of the system.

- **Fix:** The authors should note that while natural CO₂ sinks in the land biosphere and ocean have absorbed roughly 50% of anthropogenic emissions since the late 1950s, the nature, location and biophysical processes controlling the land biospheric sinks are now changing rapidly in response to human activities (e.g., deforestation, forest degradation) and climate change. These rapid changes compromise our ability to predict the efficiency of these critical sinks in the future as climate continues to evolve in response to anthropogenic greenhouse gas emissions (Liu et al., 2017, 2020; Poulter et al., 2014; Sitch et al., 2015).
- **Page:** 18
- **Comment Type:** Technical
- **Comment:** The subsections titled “CO₂ uptake by land processes” and “CO₂ uptake by ocean processes” focus on the carbon cycle models used by the Global Carbon Project. For both land and ocean, they note that this set of models predicts a range of estimates for the decadal uptake of CO₂ by the land and ocean carbon sinks. They use these results to foster doubt in the utility of these methods for predicting future change in the carbon cycle as it responds to climate change. This is misleading to the reader, because they fail to note that

all of the Dynamic Global Vegetation Models (DGVMs) included in this set include CO₂ fertilization – a mechanism that the authors of this document advocate as a key benefit of increasing atmospheric CO₂ amounts (Bastos et al., 2019).

In general, this entire sub-section illustrates a very poor understanding of existing observations and models of the global carbon cycle and their response to human activities and climate change.

Fix: Please add a sentence or sentences to explain to the reader that CO₂ fertilization is included in DGVMs, but does not necessarily enhance growth due to the other factors identified above.

- **Page:** 18, 19
- **Comment Type:** References
- **Comment:** Figures 3.2.3 and 3.2.4 cannot be found in Friedlingstein et al. 2024.
- **Fix:** Please be more clear about the source of these figures and data. For instance, if it is from a figure in Friedlingstein et al. 2024, please cite the specific figure. If the authors downloaded data themselves and made this plot, please give the link or location of the data from where it was downloaded.

Comments on Other Chapters

- **Page:** 3
- **Comment Type:** Technical
- **Comment:** Chapter 2, section 2.1 (and chapter 9) assert that CO₂ fertilization will increase plant growth and crop yields. The proposed benefits of CO₂ fertilization are not realized in the DGVMs described on pg 18 because CO₂ availability is only one of several mechanisms that control plant growth. As any farmer knows, plant growth is rarely limited by the abundance of the most abundant nutrient. It is usually limited by the abundance of the least abundant nutrient. While increased CO₂ can accelerate plant growth in carefully controlled laboratory conditions, this rarely happens in nature or in large-scale agriculture. In most natural settings, plant growth is usually limited by water, nitrogen, phosphorus, sunlight or temperature. DGVMs include all of those effects (Vitousek et al., 2010; Worden et al., 2021; Yuan et al., 2019). The range of outputs produced by the models reflects uncertainties in the relative roles of these processes and their potential evolution with climate change. This behavior should foster serious concern (doubt) about the potential benefits of CO₂ fertilization in a changing climate. There is no discussion of this here or in chapter 2.1 or in Chapter 9.
- **Fix:** The authors should clearly qualify their statements on CO₂ fertilization, recognizing that in the presence of increasing atmospheric temperature or limitations in water, sunlight,

nitrogen or phosphorus, increasing the atmospheric CO₂ concentration is more likely to impede than promote the growth of plants.

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3.3 Urbanization influence on temperature trends

John M. Wallace and Chan-Pang Ng

1. Introduction

The authors devote an entire section of the report to the urban heat island effect (UHI), which might seem to some readers like an esoteric technical issue. This section is not a distraction: along with Section 8.3, its purpose in the report is to cast doubt on observations documenting the rise of surface air temperature in response to the burning of fossil fuels.

The UHI is defined in the DOE report's glossary as "The tendency for inhabited areas to be warmer than their rural surroundings, due to the replacement of natural land and vegetation with roads, parking lots, buildings, and waste heat sources." None of these factors significantly warm the global atmosphere, but they conspire to create a shallow layer of relative warmth below the nighttime temperature inversion over cities and suburbs.

The authors devote this section to critiquing the various attempts to evaluate the influence of urbanization upon the trends in surface air temperature, concluding with the cautionary statement, "...while there is clearly warming in the land record, there is also evidence that it is biased upward by patterns of urbanization and that these biases have not been completely removed by the data processing algorithms used to produce climate data sets."

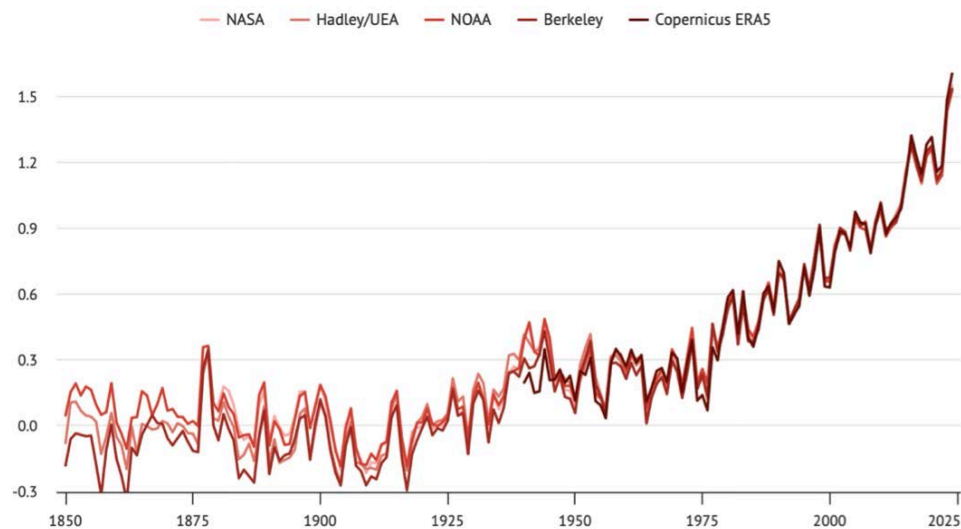


Figure 1. Annual mean, global mean surface air temperature as analyzed by the research groups listed in the legend. From the Berkeley Earth website. Temperatures are anomalies in °C relative to the 19th century.

Let's have a look at the data. Figure 1 shows extended time series of global mean surface air temperature computed by various climate centers, as indicated in the legend. In the 50-year

interval from the end of the hiatus in the mid-1970s to the present, global mean temperature has risen by almost 1°C.

Figure 2 shows the Berkeley Earth time series partitioned into the contributions from land and ocean grid points. During the 50-year interval 1975-2025, land temperatures have risen by ~1.5°C.

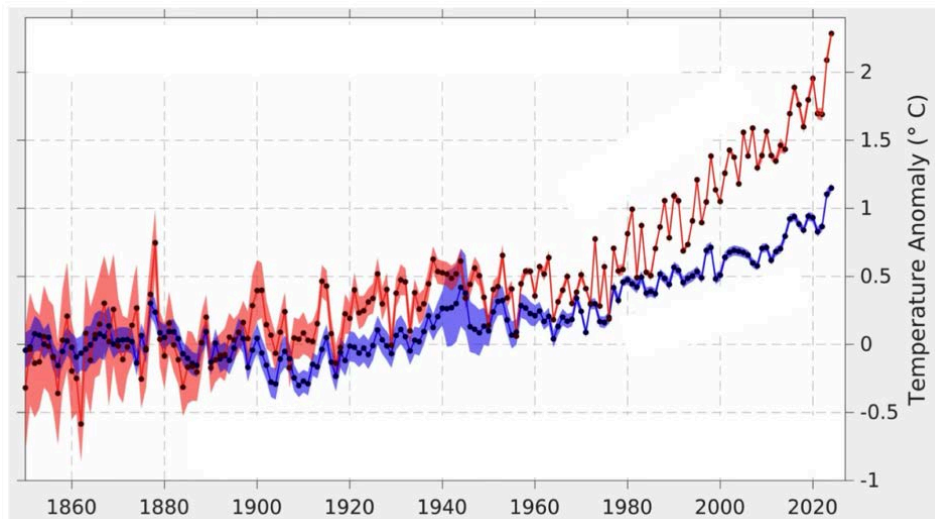


Figure 2. Time series of global mean surface air temperature. The red curve shows the average of land grid points, and the blue curve shows the average of ocean grid points. From the Berkeley Earth website. Temperature anomaly is once again relative to the late 19th century.

Figure 3 shows the geographical distribution of warm season (May through September)¹ surface air temperature trends expressed in °C per 50 years over the continental United States based on Berkeley Earth and ERA5. The warming is larger in the ERA5, but the large-scale patterns are similar in the two datasets, with warming throughout the country, strongest at the western and south-central states. The patterns based on the Hadley, GISS, and NOAA datasets (not shown) are similar.

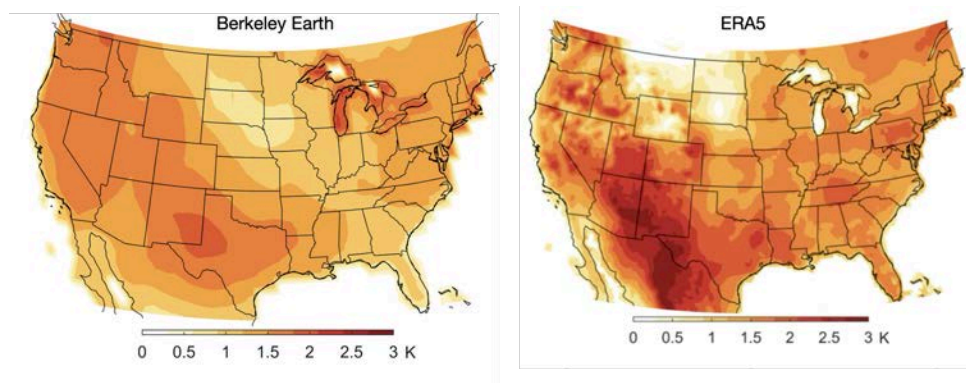


Figure 3 Warm season (May through September) surface air temperature trends based on Berkeley Earth and ERA5, in units of °C per 50 years.

¹ We show warm season means rather than annual means, because it is during the warm season that we experience the adverse impacts of extreme heat.

Averaged over the continental United States, the 50-year trend is somewhat larger in ERA5 than in the climate models. ERA5 exhibits more structure on scales of a few hundred km or less than the climate datasets because it's not subject to the spatial smoothing inherent in producing the observational datasets.

If the UHI were really producing a significant warm bias in the surface air temperature trends, one would expect the warming to be less prominent above the shallow nighttime temperature inversion. Figure 4 compares the pattern of 50-year temperature trend on the 123rd model level of ERA5 with the surface air temperature trend. This model level is about 500 m above the Earth's surface irrespective of the land elevation. That the two patterns are very similar indicates that the pattern of surface warming extends deep into the atmosphere.

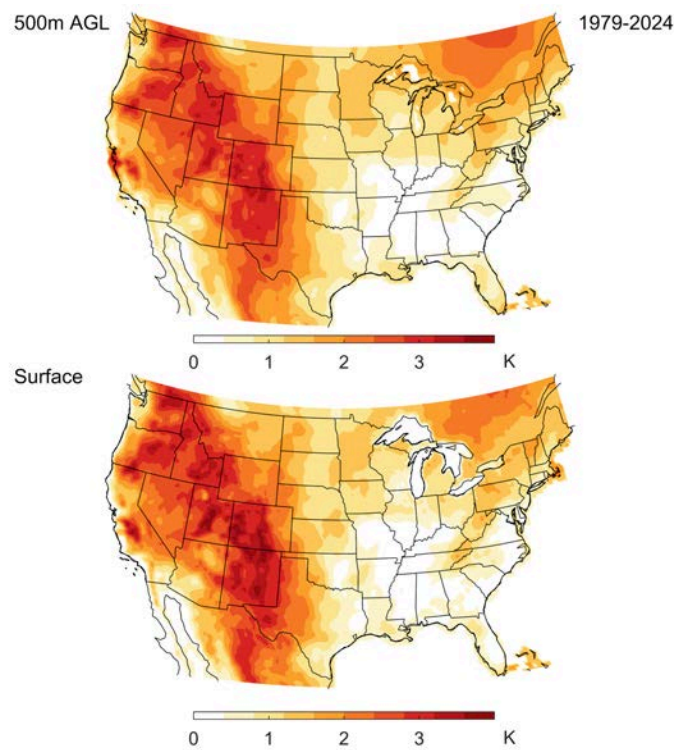


Figure 4. Annual mean temperature trends ($^{\circ}\text{C}/50$ years), 1975-2024 in the ERA5 reanalysis: 2 m above the Earth's surface and on the 123rd model level, which is about 500 m above ground level irrespective of surface elevation.

The pattern of temperature trends in Figs. 3 and 4 bear no obvious relation to the pattern of population density over the continental United States, shown in Fig. 5.

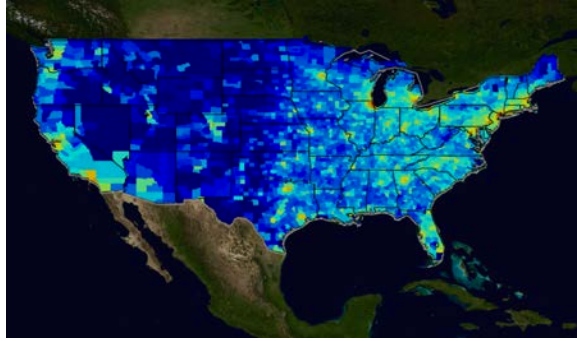


Figure 5. Population density over the continental United States based on the 2001 census. Provided by NASA's Scientific Visualization Studio.

Magnitudes of the 100, 75, 50, and 25-year trends in surface air temperature averaged over various domains and seasons based on Berkeley Earth are summarized in Table 1. The bolded values are consistent with the trends shown in Fig. 1. The trends are accelerating, as evidenced by the monotonic increase in the scaled values in all rows from the first to the fourth columns. The trends over the US exhibit little seasonality, except from 1999 onward, when the warm season trends have been larger than the cold season trends.

Table 1. Surface air temperature trends based on least squares best fits of Berkeley Earth data scaled in units of °C per 50 years.

	1924-2024	1949-2024	1974-2024	1999-2024
Global mean (year-round)	0.56	0.78	1.03	1.26
Global land (year-round)	0.74	1.09	1.50	1.63
Continental US (year-round)	0.59	0.89	1.39	1.30
Continental US (May-Sept)	0.59	0.90	1.42	1.70

Conclusions

We have shown that the magnitude of warm season temperature trends over the continental US since the mid 20th century are roughly comparable that of the global trends in land temperature (compare the values in Table 1). Since 1974, warming has prevailed over the entire country, strongest in the arid and semiarid regions of the southwest and weakest in the northern Great Plains (Figs. 3 and 4). The warming extends deeper into the atmosphere than the nighttime inversion (Fig. 4). It bears no obvious relation to the geographical distribution of population density (Fig. 5).

The evidence presented here does not support the contention in Section 3.3 of the DOE Report that the temperature trends in the observational datasets exhibit a substantial positive bias because of the urban heat island effect. We accordingly reject this attempt to cast doubt upon on the reliability of observations of temperature trends and we recommend that Section 3.3 be removed from the report.

Assessment of Chapter 4 "Climate Sensitivity To CO₂ Forcing"

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Executive Summary

This assessment critically reviews Chapter 4 of the DOE report, "Climate Sensitivity To CO₂ Forcing," identifying key misrepresentations of climate science:

1. **False Dichotomy:** The report wrongly presents climate science as a conflict between "models" and "data," ignoring the consensus approach of synthesizing multiple independent lines of evidence (models, observations, paleoclimate).
2. **Cherry-Picking Evidence:** It selectively highlights evidence supporting a low Equilibrium Climate Sensitivity (ECS) while downplaying or omitting contradictory evidence, particularly regarding aerosol forcing and the pattern effect.
3. **Internal Incoherence:** The report is undermined by critical logical inconsistencies. It champions a climate sensitivity estimate that, by its own stated policy threshold, justifies the very emissions controls it argues against; it cites technical evidence on the "pattern effect", whose logical implication is a constant — not decreasing — climate sensitivity; and it applies contradictory standards by dismissing complex climate models while accepting simpler ones that fit its narrative.
4. **Misleading Focus on ECS:** The chapter's near-exclusive focus on the highly uncertain ECS metric neglects more policy-relevant metrics like Transient Climate Response (TCR) and entirely omits the crucial Transient Climate Response to Cumulative Emissions (TCRE), which underpins carbon budgets.
5. **Mischaracterization of Model Assessment:** It dismisses climate models and their "tuning" as systemic flaws, failing to acknowledge that the IPCC, and the climate science community more broadly, comprehensively assess model ensembles alongside other evidence, accounting for biases.

6. **Ignoring Recent Warming Trends:** The report's arguments for lower sensitivity overlook recent record-high global temperatures, accelerating warming, and the planet's growing energy imbalance, which might imply underestimation of future warming.

Introduction

This section critically reviews **Section 4 ("Climate Sensitivity To CO₂ Forcing")** of the DOE report “A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate” (DOE CWG). It identifies factual errors, instances of selective evidence presentation (cherry-picking), and issues with reference interpretation. We frame our assessment in sections, structured thematically by the key misrepresentations highlighted in the chapter.

Chapter 4 contains two primary summary messages, arguing that (1) data-driven estimates of Equilibrium Climate Sensitivity (ECS) are more reliable than climate models and indicate lower sensitivity, and (2) the IPCC AR6 assessment improperly raised the lower bound of likely ECS.

Our analysis finds that the chapter fundamentally misrepresents the consensus on climate sensitivity by:

1. **Creating a False Dichotomy:** It incorrectly frames science as a conflict between "models" and "data." The robust consensus, as articulated in the IPCC AR6 and the Sherwood et al. (2020) assessment, is based on the synthesis of **multiple independent lines of evidence**, including general circulation models, historical observations, and paleoclimatology.
2. **Systematic Cherry-Picking and Omission:** The chapter selectively highlights evidence and critiques that support a low-ECS narrative while ignoring or downplaying the overwhelming body of contradictory evidence and the convergence of findings that led to the AR6 conclusions. It leverages selective citation of the literature to erroneously support the author's preferred assessment of low ECS, while incorrectly and misleadingly rejecting the potential for large influence of uncertain factors which might complicate the low assessment.
3. **Misleading Focus on ECS:** The chapter's near-exclusive focus on the highly uncertain, multi-century metric of ECS is a form of issue selection bias, while neglecting more policy-relevant metrics. Minimal attention is devoted to TCR (the transient rate of warming in response to gradually increasing CO₂ concentrations). Further, the report completely fails to address the cornerstone policy metric which accurately relates cumulative carbon emissions to warming - the Transient Climate Response to Cumulative CO₂ Emissions (TCRE).

Further, the report fails to recognize that recent years have seen record high global mean temperatures, which highlight that the 1.5°C goal of the Paris agreement is almost certain to be exceeded, that prior assessed trends might have underestimated the forced warming trajectory and that significant planetary radiative imbalances may indicate additional committed warming. These

issues are all deeply uncertain, but are core topics of active research represented in the climate literature and which highlight a risk that prior assessments might have underestimated future warming potential. By failing to address these issues, the DOE CWG presents a narrative justifying complacency in the need for emissions reductions at a time when observed warming rates are a justifiable cause for extreme concern.

Furthermore, the report's central argument is logically incoherent even on its own terms. The authors frame the entire chapter around the policy relevance of Equilibrium Climate Sensitivity (ECS), stating that "no CO₂ emission controls are economically justifiable for ECS below 2.0°C" [page 25]. They then explicitly endorse the work of Lewis as their preferred alternative to the IPCC consensus, citing his analysis which "found that climate sensitivity is estimated to be much lower and better constrained... – median 2.2°C (1.8–2.7°C in the 17–83 percent likely range...)" [page 28]. The report thus concludes by championing an ECS estimate whose median value and entire likely range fall squarely within the zone where, by their own stated threshold, emission controls are economically justified. This fundamental self-contradiction reveals that the report's conclusions do not logically follow from its own preferred evidence.

This comment documents these scientific inaccuracies and omissions to ensure the official record reflects the current state of scientific understanding as represented in major assessments like the IPCC AR6 and the U.S. Fifth National Climate Assessment (NCA5). We discuss these issues below, followed by recommendations for the revision of the DOE CWG.

Detailed assessment of report conclusions

Here we expand on the key elements where we find the conclusions and assessment of the DOE CWG for chapter 4 to be incomplete or misrepresentative of best available scientific knowledge.

Comment 1: A Mischaracterization of Assessment Methodology

Reference in CWG Report: Page 25 (Summary Statements); pp. 26-28 (Detailed Argument)

Comment Type: Technical. This addresses the report's misrepresentation of how scientific assessments of climate sensitivity are conducted.

Original Text/summary statement from CWG Report: "There is growing recognition that climate models are not fit for the purpose of determining the Equilibrium Climate Sensitivity (ECS) of the climate to increasing CO₂. The IPCC has turned to data-driven approaches including historical data and paleoclimate reconstructions, but their reliability is diminished by data inadequacies."

Implementation: The critique will dismantle the **false dichotomy** between “models” and “data”. It will explain that the consensus approach, as used by the IPCC, is a **synthesis of multiple independent lines of evidence** (models, observations, paleoclimate). The implementation will clarify that models are used as crucial tools to test physical theories and are not treated as simple calculators of ECS.

Comment:

The assertion that “*climate models are not fit for the purpose of determining...ECS*” [summary statement from CWG, page 25] fundamentally misunderstands how recent climate assessments use them. The IPCC AR6 does not treat climate models as simple calculators for ECS, where the distribution of model results is taken as the final answer. In fact, the DOE report itself acknowledges that the IPCC has actively moved away from this approach, noting that that “*Because of concerns about model tuning and the high sensitivity to cloud parameterizations, AR6 (2021) did not rely on climate model simulations in their assessment of climate sensitivity, relying instead on data-driven methods*” [DOE CWG, page 27]. Models are instead used as one crucial line of evidence among several, including historical observations, paleoclimate data, and process understanding. Their primary role is to serve as laboratories for testing physical theories about climate feedback—such as those related to water vapor and clouds—which are essential components of the overall sensitivity assessment. Therefore, the chapter critiques a simplistic methodology that the scientific community itself does not use.

“Data-driven ECS estimates tend to be lower than climate model-generated values. The IPCC AR6 upper bound for the likely range of ECS is 4.0°C, lower than the AR5 value of 4.5°C. This lowering of the upper bound seems well justified by paleoclimatic data. The AR6 lower bound for the likely range of ECS is 2.5°C, substantially higher than the AR5 value of 1.5°C. This raising of the lower bound is less justified; evidence since AR6 finds the lower bound of the *likely* range to be around 1.8°C. “ [DOE CWG, page 25]

This framing is a mischaracterization of the climate science which informed AR6. The central advance of the IPCC AR6 assessment of ECS, heavily informed by a broad independent assessment process (Sherwood et al., 2020), was not a shift away from models and to historical data, as the chapter implies. Rather, it was the formal synthesis of three complementary lines of evidence ([Forster et al. 2021](#); [Sherwood et al. 2020](#)):

1. *Process Understanding*: Knowledge of climate feedbacks (e.g., water vapor, clouds, albedo), much of which is supported by theory and observational evidence and tested in climate models
2. *Historical Evidence*: The observed warming record, combined with estimates of forcings and ocean heat uptake.
3. *Paleoclimate Evidence*: Reconstructions of past climates, such as the Last Glacial Maximum and the mid-Pliocene, which provide constraints on how the Earth system has responded to past large-scale forcing changes .

Sherwood et al. (2020) demonstrated that these three lines of evidence combined provide a likely (66%) ECS range of 2.6 to 3.9°C, though different lines of evidence constrain different aspects of the distribution. As such, observed recent warming alone provides a strong lower bound, but only a weak upper bound on ECS ([Sherwood et al. 2020](#); [Armour et al. 2024](#)). By presenting these as competing methods, with models being "unfit", the DOE chapter ignores the very source of confidence in the AR6 assessment. No single line of evidence is sufficient on its own; the strength of the conclusion lies in the collective information obtained by combining sources.

The report accepts that paleoclimate data justifies lowering the IPCC's upper bound, noting that the cooling during the last glacial maximum makes very high ECS values unlikely [see discussion of last glacial maximum, page 28 of the CWG]. However, it omits the other side of that coin: that same data makes very low ECS values equally unlikely, as a low sensitivity would be insufficient to explain either the dramatic cooling of the ice age, or observed warming over the last century, as summarised by Sherwood et al. (2020): "An S [ECS] value lower than 2 K is difficult to reconcile with any of the three lines of evidence." Moreover, the comparison of past climate states to present and future climates is not a straightforward apples-to-apples comparison: necessary assumptions that must be made in order to compare the climate feedback processes in a cold climate to those in a warm climate introduce additional uncertainty, especially regarding the upper bound (Budyko, 1969; Caballero and Huber, 2013; Sellers, 1969; Shaffer et al., 2016; Sherwood et al., 2020)

The report's critique of climate models is based on a contradictory and inconsistent standard. It argues that large-scale General Circulation Models (GCMs) cannot be trusted because they do not explicitly resolve all the small-scale physical processes that determine climate feedbacks [page 26]. Yet, the report is perfectly willing to accept and promote conclusions from far simpler models — like the box energy balance model used in the Lee et al. study to analyze the pattern effect [page 28] ([Lee et al. 2024](#)). This inconsistent application of skepticism reveals that the report's standard for accepting model evidence is not based on scientific rigor, but on whether the model's conclusions align with its preferred narrative.

Comment 2: Selective Citation and Interpretation of Evidence

Reference in CWG Report: Page 25 (Summary Statement); p. 28 (Detailed Argument)

Comment Type: Reference / Technical. This targets the report's biased use of literature and downplaying of key uncertainties to support a low-ECS conclusion.

Original Text/summary statement from CWG Report: "The AR6 lower bound for the likely range of ECS is 2.5°C, substantially higher than the AR5 value of 1.5°C. This raising of the lower bound is less justified; evidence since AR6 finds the lower bound of the likely range to be around 1.8°C."

Implementation: The critique will show how the report **cherry-picks evidence**, primarily from a single author, to question the AR6 consensus. The critique will explain that this low-ECS narrative is built by selectively downplaying major uncertainties like the "**pattern effect**" and **aerosol forcing**, whose potential impacts could imply a higher ECS.

Comment:

Much of the critique of the IPCC-AR6 ECS assessment is based on a study from a single author, (Lewis, 2022) — which the DOE report uses to claim that Sherwood et al. (2020) is subject to “methodological errors, outdated input values, and use of subjective Bayesian priors in the analysis” [quote from page 28 of the CWG]. Lewis (2022) was addressed in Sherwood and Forest (2024), then further contested by Lewis (2025)

The primary issues in this debate can be categorised into 3 topics:

- The implementation of prior assumptions in Bayesian assessments of ECS.
- The role of ‘pattern effect’ on historical sea surface temperature (SST).
- The uncertainty range for historical aerosol forcing

We address each of these issues in turn, given their outsized role in the conclusions of the report and in recent literature. In both cases, the authors of the DOE CWG report make a categorical error in which they leverage selective citation of the literature to assert *high confidence* in there being a *low impact* of these processes on the historical record. In effect, they attempt to argue that since we don’t know the magnitude of the pattern effect or historical aerosol cooling, it must be zero or near-zero (in the case of the pattern effect) or much less than typically presumed (in the case of aerosol cooling). Instead, an appropriate assessment of the scientific literature would conclude substantial uncertainty that is worthy of ongoing study considering its potentially significant impact.

The choice of priors in Bayesian assessment of ECS

In Bayesian assessments of Equilibrium Climate Sensitivity (ECS), the *prior* distribution represents the initial state of knowledge before new evidence is considered; this prior is then updated by the data (via a likelihood function) to produce a final *posterior* probability distribution. Sherwood et al. (2020) (S20) employed a subjective Bayesian framework, which seeks to synthesize all available knowledge — including process understanding, historical data, and expert judgment — into a single, coherent probabilistic statement. The strength of this approach is its transparency, as it forces all assumptions to be made explicit and quantifiable.

The subsequent debate, primarily between Nicholas Lewis (Lewis, 2022, 2025) and some of the S20 authors (Sherwood and Forest, 2024), illuminates a fundamental divide in statistical philosophy. The S20 authors defend the subjective approach, arguing that expert judgment is an unavoidable and essential component of analyzing complex systems and that making these judgments explicit is a scientific virtue. S20 also did not bury this foundational assumption; their analysis included extensive robustness tests to demonstrate the sensitivity of their results to different priors, acknowledging the influential role of this choice.

In contrast, Lewis advocates for an objective Bayesian approach, whose purpose is to produce a *calibrated* statistical inference where the uncertainty ranges approximate the properties of a frequentist confidence interval. Lewis’s central critique is that the subjective priors used in S20 are subject to “evidence duplication,” where an expert’s prior belief is rationally based on the same body of evidence used to construct the likelihood, effectively double-counting the data and leading

to an overconfident result. Instead, Lewis (2022) employed a mathematically derived, noninformative Jeffreys prior, designed to let the data dominate the final posterior distribution.

This ongoing debate makes it clear that there is no universally accepted “correct” prior for ECS estimation; the choice depends on the epistemological goal of the analysis — but it is clear that estimates are sensitive to these foundational, and partly subjective, choices — and that proper assessment of prior assumptions and their influence on assessed likely ranges for ECS should be an ongoing priority in future IPCC reports.. A promising path forward involves developing physically-constrained priors, such as those derived from emergent constraints (Renoult et al., 2020), which ground the analysis in observable processes and may help bridge the divide between purely subjective belief and abstract mathematical convention.

However, we find that the DOE CWG report fundamentally misrepresents the scientific debate over the use of priors in climate sensitivity estimation by selectively platforming Lewis’ work to advance a low-ECS narrative. The report frames Lewis’ (2022) critique of the S20 as a correction of “methodological errors... and use of subjective Bayesian priors,” thereby positioning the S20 study (and the IPCC AR6 consensus) as scientifically unsound. This is a systematic oversimplification of a deep and ongoing debate between two distinct statistical philosophies.

The Jeffreys prior (Jeffreys, 1946) used by Lewis prioritizes producing a calibrated inference where the data drives the result. However, while mathematically elegant due to their invariance properties, Jeffreys priors are not always appropriate, particularly for complex, well-studied systems like the Earth's climate because they are derived solely from a model’s mathematical structure, and can be notoriously difficult to compute for high-dimensional models (Simpson et al., 2017). In contrast, the expert prior used in the Bayesian approach of S20 aims to transparently synthesize all available knowledge including expert judgment through a well established process known as prior elicitation (O’Hagan et al., 2006). By making expert judgments explicit and quantifiable, the subjective Bayesian framework allows for the synthesis of multiple independent lines of evidence, leading to more robust and scientifically coherent conclusions (Annan and Hargreaves, 2006). Therefore, the use of subjective priors is not an introduction of arbitrary bias, but rather a principled choice to ensure that statistical inference remains grounded in physical reality and leverages the full scope of scientific understanding.

The DOE CWG vastly simplifies this debate by repeating Lewis’ critique of “evidence duplication” but failing to acknowledge the S20 authors’ defense of their Bayesian methodology (Sherwood and Forest, 2024) or to note that S20 included extensive sensitivity analyses on their choice of priors. As such, the report uses a soundbite from complex scientific discussion as a rhetorical tool to cast doubt on a well-reasoned consensus rather than attempting to offer a balanced assessment. The goal of S20 and the IPCC was to make a general scientific assessment that requires synthesizing disparate lines of evidence—from paleoclimate proxies to satellite observations to complex model simulations—each with its own deep, unquantifiable uncertainties.

As such, in the case of S20, the expert prior is not an introduction of arbitrary bias, but a necessary tool to ensure the statistical result remains grounded in the full scope of physical understanding that cannot be captured by the simplified equations alone. The Jeffreys prior is derived solely from the structure of the chosen statistical model; if that model is an acknowledged simplification of reality, a prior based upon it is not necessarily more robust than one informed by the collective expert judgment of the field. Therefore, the subjective/expert guided Bayesian framework remains

a scientifically coherent and appropriate methodology for a task that is fundamentally about the synthesis of all available knowledge. In any event, it is acknowledged in Lewis (2022, 2024) that the adoption of objective priors has limited impact on the ECS median and confidence interval range (in fact both the range and median *increase* using an objective Jeffreys prior), such that these choices are broadly and quantitatively inconsequential to our understanding of ECS.

The role of the pattern effect

A crucial uncertainty in the quantification of ECS, in discrepancies between data-driven and model-driven ECS estimates, and between the aggregated estimates of Sherwood et al. (2020) and Lewis (2022), is the future evolution of sea surface temperatures in the equatorial Pacific Ocean. As the DOE CWG report notes [page 28 of the CWG], whether the historical spatial pattern of warming in the equatorial Pacific Ocean is consistent with the future spatial pattern of warming is critical in our overall estimate of ECS (a phenomenon known as the pattern effect). The DOE CWG report cites two studies that variously argue that models may misrepresent future warming patterns (Seager et al., 2019) and that the historical warming pattern may be expected to continue (Lee et al., 2024). They leverage these studies to argue that ECS is lower than implied by modelling studies, Sherwood et al. (2020), AR6, and the general scientific consensus. *[We note in addition that the citation in the DOE CWG for Lee et al. (2024) points to a paper that does not exist. The presumed correct citation, which has a different author list and journal information compared to the citation in the DoE CWG report, is “Lee, S., Bannan, P.R., Park, M., Clark, J.P., 2024. Zonal Contrasts of the Tropical Pacific Climate Predicted by a Global Constraint. Asia-Pac J Atmos Sci 60, 669–678. [<https://doi.org/10.1007/s13143-024-00373-5>]*

The report's handling of Seager et al. (2019) exemplifies this misrepresentation. The DOE CWG claims the paper shows that “contrary to models, the west-east temperature gradient has been strengthening over time” and that there is “no reason to expect the gradient to weaken” [page 28]. This is a direct contradiction to (Seager et al., 2019), who state “On decadal time scales, an overall stronger than normal SST gradient since 1998 has... **temporarily** reduced the rate of global warming in the atmosphere by enhancing the rate of ocean heat uptake” — thus not implying permanence of the enhanced temperature gradient (see the independent technical comment to the CWG on this matter by Clement et al. for additional context).

The DOE CWG report's choice to emphasize this single study, and over-emphasize their findings by omitting the authors own caveats, is an indicative case of cherry-picking from the scientific literature. In contrast, a large number of recent papers note the importance of the pattern effect in supporting the potential for a higher ECS than implied by historical observations (Alessi and Rugenstein, 2023; Andrews et al., 2018; Armour et al., 2013; Dong et al., 2021; Gregory and Andrews, 2016; Liang et al., 2024; Marvel et al., 2018; Marvel and Webb, 2025; Modak and Mauritsen, 2023; Myers et al., 2023; Olonscheck and Rugenstein, 2024; Rose et al., 2014). The DOE chapter dismisses this critical finding based on a narrow and contested interpretation of recent trends, failing to represent the full scope of the scientific debate and the physical reasoning behind the pattern effect adjustment in AR6. Several comprehensive reviews of all sides of this issue have been published, and were likewise not cited in the DOE CWG report (Lee et al., 2022; Watanabe et al., 2024).

The CWG also fails to include the full context from some of the cited sources for this debate in order to produce a narrative of false confidence in the assertion that pattern effects have had a

minimal influence on past temperature trends. For example, the CWG excludes the bold portion of the following quote from (Lee et al., 2024): **“While maxMEP solutions in general cannot provide a definite answer to the problem, these model results strengthen the possibility that the trajectory of the observed trend reflects the response to increasing GHG loading in the atmosphere.”** Lee et al. (2024) also highlight the limitations of their idealized approach to make statements about real-world trends in their conclusions: “As was stated in the introduction, we view the maxMEP solution as a statistical inference rather than a definite answer. The prediction made by maxMEP is as good as how accurately our idealized climate system captures the essence of the real climate system. The model considered in this study does not, at least explicitly, include numerous processes that probably play a role in determining how the real tropical Pacific responds to GHG warming; ocean dynamics, moisture dynamics, planetary-scale wave dynamics, stratospheric dynamics, etc.”

It is certainly the case that there is uncertainty about the future evolution of sea surface temperatures in the equatorial Pacific with major consequences for ECS and warming rates. However, the report’s presentation of this issue represents a highly selective and misleading interpretation of the scientific literature. However, the authors of Forster et al. (2021) were fully aware of the warming pattern biases in current climate models. Their conclusion that the pattern effect is likely to increase warming was not made in ignorance of this fact but in spite of it. The AR6 assessment weighed multiple lines of evidence ([Forster et al. 2021](#); [Sherwood et al. 2020](#)) :

- The physically-based understanding of how the tropical climate system responds to strong warming.
- The behavior of a wide ensemble of climate models.
- The historical record, including the understanding of its limitations in representing the forced response due to internal variability.

The consensus conclusion was that, for long-term projections, the physically-based mechanisms pointing to a future weakening of the gradient are a more robust guide than simply extrapolating a recent trend that is likely contaminated by natural decadal cycles. The DOE report presents this complex scientific judgment as a simple error, thereby misrepresenting the rigorous nature of the IPCC assessment process.

The report’s narrow focus on the east-west tropical Pacific temperature gradient as the sole determinant of the pattern effect is also a critical oversimplification [**page 28**]. A physical mechanism for the increase of climate sensitivity over time has been proposed as the slow warming of ocean heat uptake regions, particularly the Southern Ocean and the North Atlantic (Armour et al., 2024). These high-latitude regions have weaker negative cloud feedbacks compared to the tropics, meaning that, as they eventually warm, the planet’s overall climate sensitivity will rise as patterns of warming change (Rose et al., 2014). The DOE report's failure to engage with this primary mechanism indicates a superficial and biased assessment of the issue, while wider literature has examined this topic extensively (Watanabe et al., 2024).

Even within the flawed framework of focusing only on the tropical Pacific, the report's logic is unsound. For the pattern effect to cause a decrease in future ECS, the spatial pattern of warming would have to change. This would require the east-west temperature gradient to strengthen superlinearly relative to global warming (Dong et al., 2019). However, Lee et al. (2024), cited

extensively by the report [page 28], suggests the gradient scales linearly with forcing (e.g., see their Fig. 4). A linear scaling is consistent with a constant warming pattern, and therefore a constant ECS. The report thus cites evidence that contradicts its own implication that ECS might be lower than current estimates.

The DOE CWG extends the narrative of its assessment of IPCC ECS ranges to critique the CMIP6 ensemble, citing Scafetta (2022), which finds that most CMIP simulations warm too much over recent decades — and similar arguments have been made to dismiss the plausibility of high ECS models (Hausfather et al., 2022). However, this assessment ignores the role of the biased warming patterns in current generation models (Armour et al., 2024) which is likely to have suppressed observed warming, implying “observed warming is consistent with wide ranges of ECS and TCR extending to higher values than previously recognized.” In short, the report fails to acknowledge that recent science has found differences between the patterns of warming seen in models and the real world, and these differences imply that past simulated global warming rates cannot be easily used to rule out models which warm a lot in the future.

Assumptions on aerosol forcing

The assumed strength of the cooling effect from aerosols is a critical ‘lever’ in any energy-budget estimate of climate sensitivity, and disagreements over this value explain a significant portion of the difference between recent studies. A weaker assumed aerosol cooling effect necessitates a lower climate sensitivity to explain the observed historical warming, and vice-versa (Smith et al., 2021). Sherwood and Forest (2024) point out that a key reason Lewis (2022) arrives at a lower Equilibrium Climate Sensitivity (ECS) is his “downward revision of expected historical aerosol cooling”. In direct contrast, Wall et al. (2022) finds a “stronger mean of aerosol cooling and thereby a slightly higher ECS” from the same historical record. This demonstrates clearly that the resulting ECS estimate is directly dependent on the chosen aerosol forcing value.

The core of the issue is that the precise magnitude of the net cooling from aerosol-cloud interactions remains one of the largest uncertainties in climate science. Even recent studies are grappling with this complexity. For example, Sherwood and Forest (2024) note that the Wall et al. (2022) study, despite finding stronger cooling, is itself incomplete, as it “only considered sulfate effects on shallow clouds, which ignores potentially large effects from less well-understood cloud–aerosol interactions”. This is consistent with the wider literature, including major reviews such as Bellouin et al. (2020) and more recent work like Quaas et al. (2022), which confirm that constraining the exact cooling effect from aerosols based on observations remains a frontier of research. Therefore, the choice of any single value or distribution for aerosol forcing is a significant judgment call by the authors that heavily influences the final climate sensitivity estimate. This is a real and important source of uncertainty that should not be eliminated by simply choosing a desired value.

While the DOE report verbally concedes that aerosol forcing is the “greatest source of uncertainty” in data-driven methods [page 27, CWG], its conclusions fail to represent this uncertainty adequately. The report correctly identifies the fundamental trade-off, stating that observed warming can be consistent with either “low ECS and low aerosol cooling, or high ECS and high aerosol cooling” [page 28, CWG]. However, having established this ambiguity, the chapter proceeds to build its entire narrative around evidence supporting only one side of that trade-off—the “low-low” scenario—by exclusively platforming analyses like Lewis (2022) that

rely on weaker aerosol cooling to derive a lower ECS. It does not give equal weight to the body of evidence supporting a stronger aerosol cooling effect, which would imply a higher ECS. In this way, the report uses the *existence* of uncertainty as a rhetorical tool to cast doubt on the consensus, while its own conclusions reflect a selective and unbalanced resolution of that same uncertainty.

Comment 3: Inadequate assessment of Policy-Relevant Metrics

Reference in CWG Report: General focus on ECS (pp. 25-28) and brief treatment of TCR (p. 29); omission of TCRE.

Comment Type: Issue Selection Bias. This addresses the report's strategic focus on an uncertain metric to the exclusion of more policy-relevant ones.

Original Text/summary statement from CWG Report: The chapter's near-exclusive focus is on the uncertainties and debates surrounding the Equilibrium Climate Sensitivity (ECS) metric. The report acknowledges that the Transient Climate Response (TCR) is a “more useful observational constraint”.

Implementation: The critique will state that focusing almost entirely on the highly uncertain ECS metric is a form of bias that maximizes the appearance of scientific disagreement. It will highlight the **striking omission** of the **Transient Climate Response to Cumulative Emissions (TCRE)**, which is the scientific foundation for carbon budgets and the Paris Agreement.

Comment:

The DOE report dedicates the vast majority of its chapter to the uncertainties surrounding ECS. The arguments about model fitness, data-driven methods, the pattern effect and observational constraints are all focused on this single, long-term, and most uncertain metric. The report's bias is made clear by its own admission in its very brief section on the Transient Climate Response (TCR) which is acknowledged as a “more useful observational constraint” [page 29, CWG] than ECS and is “better constrained by historical warming” [page 29, CWG]. The decision to relegate the TCR metric to a short, concluding section, while focusing almost entirely on the more uncertain and less policy-relevant metric, is a clear example of issue selection bias. This framing allows the report to maximize the appearance of scientific disagreement and uncertainty, creating a misleading impression that the “consensus” view is in error or misleading.

Perhaps the most striking omission in the chapter — and the entire report — is the complete failure to mention the **Transient Climate Response to Cumulative Emissions (TCRE)** or the related **Zero Emissions Commitment (ZEC)**. The TCRE provides the direct, near-linear relationship between the total carbon ever emitted and the peak warming experienced (Allen et al., 2009; Matthews et al., 2009), and it is the scientific foundation upon which all carbon budgets are built (Damon Matthews et al., 2021; Jones and Friedlingstein, 2020). The ZEC concept confirms that global warming will largely cease once net-zero CO₂ emissions are reached, providing the physical basis for “net-zero” as a viable policy goal (Palazzo Corner et al., 2023). Together, these two concepts form the central scientific framework underpinning the entire Paris Agreement (Rogelj et al., 2019), as they are the internationally accepted tools used to translate temperature targets into

actionable emissions policies. For a report claiming to be a “Critical Review” of greenhouse gas impacts, to entirely ignore the primary scientific framework for international and national climate policy is an **inexplicable and scientifically unjustifiable omission**.

This biased framing stands in sharp contrast to the approach taken by Masson-Delmotte et al. (2023) and the USGCRP (2023), which provided a balanced treatment of all relevant metrics, using them to answer different questions. Crucially, in their policy-facing summaries (like the IPCC’s Summary for Policymakers), they give prominence to the TCRE relationship and the resulting carbon budgets. They do this because that is the most actionable and relevant information for policymakers working to meet specific warming targets like 1.5°C or 2.0°C. They do not share the DOE report’s selective and biased focus on ECS-related debates.

Comment 4: Climate model ECS is not generally ‘tuned’

Reference in CWG Report: Pages 26-27

Comment Type: Technical. This addresses the report’s mischaracterization of climate model development and its use in consensus assessments.

Original Text from CWG Report: "...the MPI modelers chose an ECS value of 3°C and then tuned the cloud parameterizations to match their intended result."

Implementation: Our critique will explain that the report uses the transparent practice of model "tuning" in one specific instance to imply a systemic flaw across all models. It will clarify that the IPCC process does not simply average model outputs but assesses the full ensemble in context with all other lines of evidence, explicitly accounting for known biases like the "hot model" problem.

Comment: The DOE report suggests the practice of "tuning" processes, which sets ECS in one specific model (Mauritsen and Roeckner, 2020), as evidence of a systemic flaw rather than transparency in the model development process, while also failing to acknowledge that model calibration is highly diverse amongst centers (Schmidt et al., 2017), and that the IPCC process (more so than ever in AR6) assesses the full ensemble in context with other evidence, rather than assessing the distributions of outcomes from CMIP itself.

The report’s implicit assertion that climate models are "tuned" to specific ECS values is a faulty generalization and a mischaracterization based on a single example of the MPI model (Mauritsen and Roeckner, 2020) [page 26]. Firstly, in the MPI model, as for other Earth System Models, there is no single parameter for ECS. ECS is an emergent property, and is modulated by a set of interacting feedbacks in different components of the climate system. Some of the component representations in the model may have free parameters which could potentially change the strength of those feedbacks in the model, and therefore change the climate sensitivity (Sanderson et al 2008)

In the case of the MPI model, the ECS was not directly tuned to match a particular desired value, as the authors of (Mauritsen and Roeckner, 2020) note: “the target in the tuning was not a particular climate sensitivity, rather it was an improved match to the instrumental record, and

changing the climate sensitivity was a means to that end.”. As such, the model developers chose to adjust cloud parameters, which improved the historical warming simulation, and those parameters also influenced the diagnosed ECS of the model.

Secondly, if tuning to a desired ECS value was generally commonplace, the CMIP6 ensemble would not exhibit the well-documented "hot model" problem, where numerous models from diverse international institutions produced ECS values higher than previous IPCC assessed ranges. The very existence of this wide ECS spread in CMIP6 (Meehl et al., 2020) is therefore direct evidence against the concept that universal tuning of ECS is commonplace.

Furthermore, for climate risk assessment and constraint of real-world response, as well as to improve modeled historical warming representation, the ability to tune ECS to different levels would actually be useful, but this is in most cases a highly non-trivial exercise, given that relevant parameters are generally not *a priori* known without performing large parameter perturbation ensembles, and adjusting comparable parameters in different models has very different effects on ECS ([Sanderson 2011](#)). Furthermore, even if parameters which influence ECS can be identified, they often also exert strong influence on climatological performance (Peatier et al., 2022), which means that ECS cannot be easily altered without degrading the past and present performance of the model. In short, even if it were desired for specific purposes, tuning ECS is a highly complex undertaking, requiring dedicated non-standard experiments and huge computational resources to isolate the parameters that significantly influence ECS. Thus, contrary to what is implied in the DOE CWG report, this practice is not commonplace in model development.

In summary, the DOE report's suggestion that climate models are systematically rigged to a desired sensitivity is a false generalization. It mischaracterizes a single example where parameters were adjusted to improve historical performance, and those parameters also impacted ECS; i.e. ECS was not directly “tuned” as the report implies.. The wide diversity of results from different international modeling centers is direct evidence *against* a coordinated "tuning" effort. In reality, deliberately tuning for a specific climate sensitivity is technically very difficult, and is not a standard practice, nor is it a priority for model developers who are largely motivated with maximising the consistency of model simulations with observations (Schmidt et al., 2017, Mauritsen et al, 2012). The appropriate viewpoint for assessing ECS in the CMIP ensemble is to consider it as a broad, emergent feature of simulations that each attempt to faithfully reproduce the observed climate and its historical trends.

Comment 5: Omission of Current Observational Context

Reference in CWG Report: The entire chapter (pp. 25-30) lacks this context.

Comment Type: Technical / Omission. This addresses the report’s failure to connect its theoretical arguments to accelerating real-world observations.

Original Text/summary statement from CWG Report: The chapter’s entire discussion of climate sensitivity is framed through historical data and model disagreements, without reference to accelerating real-world warming trends.

Implementation: The critique will point out that the report's arguments for lower sensitivity are made in a vacuum, **ignoring the context of recent record-breaking global temperatures**, the planet's large and growing energy imbalance, and evidence that warming may be accelerating. This omission makes the report's narrative of complacency scientifically unjustifiable.

Comment:

The DOE report's intense focus on a precise value for the long-term, multi-century metric of ECS is a distraction from the more immediate evidence that the climate system is presently warming rapidly. Global temperatures are approaching 1.5°C and already likely have exceeded this level during a 12 month period (Bevacqua et al., 2025; Cannon, 2025), with some evidence that the rate of warming has accelerated (Samset et al., 2023). This recent acceleration follows a period where a specific pattern of sea surface temperatures after 1998 may have temporarily suppressed surface warming by increasing the reflection of sunlight from low clouds (Zhou et al., 2016). However, evidence suggests this period is over, with the pronounced warming of 2023–2024 being associated with a large reduction in the reflection of shortwave radiation from clouds (Goessling et al., 2025). This is happening while the planet maintains a large and growing positive energy imbalance, with the Earth system continuing to accumulate heat which commits the planet to further warming (Hodnebrog et al., 2024; von Schuckmann et al., 2023). Therefore, the DOE report's focus on historical disagreements to support a lower-end sensitivity estimate fails to include the context of recent observational global temperature trends.

Growing evidence for the intensification of global warming over recent years increasingly challenges conclusions about the magnitude of climate sensitivity that were derived from the comparatively slower warming rate over prior decades. While the formal incorporation of these recent trends into long-term ECS estimates is an ongoing process, absence of any discussion of recent accelerations in warming in any "Critical Review" is a significant flaw.

Recommendations

To address the aforementioned errors, omissions, and bias, the authors of the DOE CWG report need to:

1. Remove assertions of a dichotomy between model and data-derived ECS. - They should instead acknowledge and highlight the widely adopted and scientifically robust approach of recognising all available information in concert, while assessing uncertainties in each. The revision must acknowledge that the scientific consensus on Equilibrium Climate Sensitivity (ECS), as established by the IPCC AR6 and other major assessments, is not based on choosing one method over the other. Instead, its strength lies in the synthesis of multiple, independent lines of evidence, including climate models, historical observations, paleoclimate records, and process understanding. The report should be amended to reflect that models are used as crucial tools to test physical theories, and are not used as calculators of ECS.

2. Correct selective citation of literature that supports their preferred conclusion of a low ECS. - The current text selectively cites literature that supports a low-ECS narrative while downplaying or omitting contradictory evidence. To correct this, the report must incorporate the full scientific debate on key uncertainties, particularly:

- *Use of priors:* The report should avoid misrepresenting the use of subjective Bayesian priors in consensus assessments as a "methodological error." Instead, it should acknowledge the ongoing and nuanced debate in statistical philosophy and consider the explicit sensitivity analyses performed in such assessments, rather than selectively critiquing their application to support a specific narrative.
- *Aerosol Forcing:* Acknowledge that the magnitude of aerosol cooling is a primary source of uncertainty and that assuming a weaker cooling effect (which leads to a lower ECS) is a critical judgment call, not a settled conclusion.
- *Pattern Effect:* The dismissal of the "pattern effect" based on a narrow interpretation of recent trends is highly misleading as it excludes a major source of uncertainty about how historical warming rates can be accurately used to quantify climate sensitivity. The revision should include the significant body of evidence and physical reasoning suggesting that historical warming patterns have likely suppressed observed warming, meaning ECS could be higher than historical data alone suggest.

3. Broaden the focus to include policy-relevant metrics - The report's near-exclusive focus on the uncertain, long-term ECS metric is a form of issue selection bias that exaggerates scientific controversy by highlighting a metric which has only minimal policy relevance. The document must be revised to include a thorough discussion of more policy-relevant metrics that are better constrained by observations. This includes not only the Transient Climate Response (TCR), which the report itself calls a "more useful observational constraint", but also, most critically, the Transient Climate Response to Cumulative Emissions (TCRE) - which is the quantity which underpins understanding of how remaining carbon budgets relate to warming thresholds.

4. Explicitly acknowledge and address how model biases are addressed in assessments. The report should refer to the fact that, in IPCC AR6, inconsistencies between models and observations and potential biases in model climate sensitivity values are taken into account in assessments of future climate change. The CMIP6 historical simulations assessed in IPCC AR6 have an ensemble mean global surface temperature change within 0.2°C of the observations over most of the historical period, and observed warming is consistently captured by the CMIP6 model spread (Eyring et al., 2021). Biases are assessed to be small enough to support detection and attribution of human-induced warming (very high confidence). IPCC AR6 clearly notes that some CMIP6 models simulate a warming that is either above or below the assessed very likely range of observed warming. However, this information about how well models simulate past warming, as well as other insights from observations and theory, are used to assess projections of global warming (see Cross-Section Box TS.1 in [\(Arias et al., 2023\)](#)).

5. Show consistency in discussing the implications of sensitivity. The report makes clear that sensitivity metrics are useful for assessing the danger of CO₂ pollution and the need for "climate action," but are internally inconsistent about the implications of the metrics they assess, claiming that 2°C ECS is the threshold below which emissions controls are unnecessary (Dayaratna et al., 2017, 2020), but then that ECS is likely above 2°C (Lewis, 2022). In addition to using more policy-relevant metrics for the danger of CO₂ (such as TCRE; see point 3 above), the authors should be explicit in their assessments of these metrics and their relation to the thresholds for societal danger.

Suggested update to summary statements

Given the above we suggest the following update to the Chapter 4 summary statements:

- **On the Scientific Assessment of Climate Sensitivity:** The scientific consensus on Equilibrium Climate Sensitivity (ECS), as established by the IPCC AR6, is based on **synthesizing multiple independent lines of evidence**, including climate models, historical observations, and paleoclimate records. This approach avoids relying on any single method, using climate models as essential tools for understanding physical processes and feedbacks rather than as direct calculators of ECS. While each line of evidence has uncertainties, their combination provides a more robust assessment than any individual method alone.
- **On the Assessed Range of Climate Sensitivity:** The IPCC AR6 assessed a likely ECS range of 2.5°C to 4.0°C, narrowing the uncertainty by constraining both the high and low ends. This was achieved by combining evidence from paleoclimate, which makes very high sensitivity unlikely, with historical warming and process understanding, which make very low sensitivity unlikely. This assessment accounts for major uncertainties, such as the magnitude of aerosol cooling and the "pattern effect," acknowledging that selectively downplaying these factors can lead to biased, artificially low ECS estimates.
- **On Policy-Relevant Climate Metrics:** While ECS is a useful metric, climate policy and near-term warming projections are better informed by metrics like the Transient Climate Response (TCR) and the **Transient Climate Response to Cumulative Emissions (TCRE)**. The TCRE, which establishes a direct link between total CO₂ emissions and global warming, is the fundamental scientific basis for carbon budgets and international climate targets like the Paris Agreement. A complete assessment of climate sensitivity must include these policy-relevant metrics.

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Technical Comment on Page 28 , Section 4.3 'Data-driven estimates of climate sensitivity'

By Amy Clement, Ph.D., Richard Seager, Ph.D., Adam Sobel, Ph.D., Mark Cane, Ph.D., Jeremy Klavans Ph.D.

The DOE report cites Seager et al. (2019) in Section 4.3 to counter AR6's claim that a weakening tropical Pacific SST gradient would raise climate sensitivity. They say that the gradient has actually strengthened, likely due to misrepresented ocean dynamics in models, implying climate sensitivity could be lower than current estimates.

However, the Seager et al. (2019) finding, that the Pacific equatorial sea surface temperature gradient has increased in the real world but not models, does not support a lower estimation of equilibrium climate sensitivity (ECS) than those produced by the models. It is not clear that this increased gradient will persist in the future especially as the temperature of subsurface waters that upwell at the Equator increases (Held 2010, An et al. 2012, Heede et al. 2021). Even if the strengthened gradient does persist it is not clear what its effect is on clouds and water vapor and, therefore, ECS. There are competing effects of local versus tropics-wide processes on equatorial cloud cover (e.g. Klein and Hartmann 1993, Myers and Norris 2013) and humidity (e.g. Pierrehumbert 1993, Clement and Seager 1999), and it is unknown how these will respond to the particular pattern of Pacific equatorial cooling amidst tropical warming (Jiang et al. 2024). Thus, while the strengthened gradient could imply a reduced *transient* climate response, how long it lasts, and how it impacts the *equilibrium* climate sensitivity is not known.

What is more consequential is that persistence of the strong gradient noted by Seager et al (2019) is likely to cause worsening drought in the Southwest United States (Kuo et al. 2025, Seager et al. 2023) and increasing Atlantic hurricane activity (Sobel et al. 2023), based on historical associations between these impacts and La Niña events as well as longer-term trends. These well-established and consequential linkages from the tropical Pacific are not cited in the DOE report.

In summary, the observed trend in the equatorial temperate gradient is not guaranteed to persist long into the future while its impacts on clouds and water vapor are poorly known. Therefore its effect on the future warming rate is unknown. The uncertainty in the persistence of this trend means that it cannot be used to imply a lower estimate of ECS (which relies on future temperature trends). However, it is clear that the strengthened equatorial gradient in response to anthropogenic forcing drives significant and costly alterations to U.S. climate via its impact on drought and hurricanes. These points should be included in the report, including the implications for the main findings of the report.

We also note that the authorship list in the cited Seager et al. (2019) is not correct. The correct citation is below.

Seager, R., Cane, M., Henderson, N. Lee, D-E, R. Abernathy, H. Zhang. Strengthening tropical Pacific zonal sea surface temperature gradient consistent with rising greenhouse gases. *Nat. Clim. Chang.* **9**, 517–522 (2019). <https://doi.org/10.1038/s41558-019-0505-x>

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Section 5.2: Surface Warming

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Summary: The DOE CWG report rightly acknowledges that it is important to benchmark model simulations of surface warming against historical observations. The authors argue that climate models, except for climate models with low climate sensitivity, overestimate surface warming from 1979 to the near-present. This incorrect claim is referenced in the DOE CWG Report's Executive Summary to conclude that models produce “exaggerated projections of future warming” (DOE CWG pg. ix). This conclusion relies on incorrect claims, ignores scientific research that helps to explain differences in model-versus-observed warming, and relies on a misleading framing that model projections are the sole source of information about future changes in climate.

The following changes must be made to Section 5.2 in the DOE CWG document and to related statements in the executive summary and chapter summary:

- **The incorrect claim that only models with the lowest ECS reproduce observed warming must be removed.**
- **Revise Figures 5.2 and 5.3 and related statements in the report to (a) use a longer reference period to compute the anomalies to ensure the influence of internal variability is minimized in model-observational comparisons (e.g. reference period 1850–1900 as in IPCC AR6), (b) show the full historical record so that model performance can be evaluated beyond the satellite era, (c) account for observational uncertainty, and (d) include representation of internal variability from the models by showing the range of anomalies and trends from individual model ensembles.**
- **The potential role of forcing biases on simulated-versus-observed warming differences must be discussed.**
- **Include statements on warming biases of climate models over longer time periods.** The CMIP6 historical simulations assessed in IPCC AR6 have an ensemble mean global surface temperature change within 0.2°C of the observations over most of the historical period, and observed warming is within the 5–95% range of the CMIP6 ensemble. Model biases are assessed to be small enough to support detection and attribution of human-induced warming (very high confidence).
- **Remove the statement on “exaggerated projections of future warming” because this assertion is an oversimplification: IPCC assessment projections rely on more**

than raw climate model output. The report should refer to the fact that in IPCC AR6, inconsistencies between models and observations and potential biases in model climate sensitivity values are taken into account in assessments of future climate change. IPCC AR6 clearly notes that some CMIP6 models simulate warming that is either above or below the assessed very likely range of observed warming. However, this information about how well models simulate past warming, as well as other insights from observations and theory, are used to assess projections of global warming (see Cross-Section Box TS.1 in Arias et al. (2021)).

These issues and necessary corrections are further detailed below.

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The authors focus on a subset of the historical period, which results in a misleading comparison of models and observations. A comparison of simulated-versus-observed warming is discussed in Eyring et al. (2021) and provides greater context:

Papalexiou et al. (2020), Tokarska et al. (2020) and Stolpe et al. (2021) all report that CMIP6 models on average overestimate warming from the 1970s or 1980s to the 2010s, although quantitative conclusions depend on which observational dataset is compared against [...]. However, Figure 3.4 [reproduced below as Figure 1], which includes a larger number of models than available to those studies, indicates that the CMIP6 multi-model mean tracks observed warming better than the CMIP5 multi-model mean after the year 2000. The CMIP6 multi-model mean GSAT warming between 1850–1900 and 2010–2019 and associated 5–95% range is 1.09 [0.66 to 1.64] °C. [...] So some CMIP6 models simulate a warming that is smaller than the assessed observed range, and other CMIP6 models simulate a warming that is larger. That overestimated warming may be an early symptom of overestimated ECS in some CMIP6 models ([...] Meehl et al., 2020; Schlund et al., 2020), and has implications for projections of GSAT changes ([...] Liang et al., 2020; Nijssen et al., 2020; Tokarska et al., 2020; Ribes et al., 2021).

While Eyring et al. (2021) acknowledge that some models may overestimate warming because they have climate sensitivity values that are too large, climate models from the Coupled Model Intercomparison Phase 6 (CMIP6) track with observations over the long-term (see Figure 1 from IPCC AR6 Fig. 3.4). This context is important because warming trends over shorter decadal or multidecadal time periods may include a substantial contribution from internal climate variability (Figure 2), which can temporarily enhance or diminish observed trends relative to the average warming simulated in models.

To correct this issue, the DOE CWG Report must include simulated and observed time series of global surface temperature anomalies over the full historical record (1850 to present) so that model concordance with observations can be assessed outside the satellite era. To mitigate the potential influence of internal variability when comparing simulated and observed time series, a sufficiently long reference period (e.g., 1979 - 2008 and 1850 - 1900) should be used. The DOE CWG report should include a balanced assessment about model performance over the full historical record, clearly noting that the CMIP6 historical simulations assessed in IPCC AR6 have an ensemble mean global

surface temperature change within 0.2°C of the observations over most of the historical period, and observed warming is within the 5–95% range of the CMIP6 ensemble.

Page 33, Technical Comment

The comparison between models and observations in the DOE CWG Report does not account for factors that help to explain differences between simulated and observed warming nor does it discuss potential flaws in ascribing model-observational differences solely to climate sensitivity biases. Research indicates that internal variability has reduced global warming over 1979 to the near-present (Po-Chedley et al. 2021, 2022; Sweeney et al., 2023). These effects are important when assessing projections of future warming. Statistical constraints on climate warming projections support greater future warming when internal variability in observations is accounted for (Liang et al. 2024). There is also evidence that discontinuities in model prescribed biomass burning aerosols has resulted in exaggerated warming in some models over recent decades (Fasullo et al. 2022; Po-Chedley et al. 2022). Another shortcoming with Section 5.2 of the DOE CWG Report is that the authors ignore uncertainty in observed trends, which makes it impossible to fairly assess model-observational trend compatibility (Schmidt et al. 2023). Despite the effects of internal variability, which appear to have reduced observed warming, and forcing biases, which may have enhanced model simulated warming, models with low, medium, and high climate sensitivity values are able to reproduce observed satellite era surface warming within observational uncertainty (see Figure 2, Fig. 3 in Tokarska et al. 2020, and Schmidt et al. 2023), which is contrary to the DOE CWG statement (page 31) that only models with the lowest ECS reproduce observed trends. In fact, in DOE CWG Figure 2 models with trends below the mean of the observations have climate sensitivity values as high as 4.9 K (Zelinka et al. 2020). The model-observational comparisons in Section 5.2 of the DOE CWG document are problematic because they do not account for internal variability, observational uncertainty (see, e.g., Menemenlis et al. 2025), and forcing biases.

To correct these issues, the DOE CWG Report must include estimates of observational uncertainty and include representation of internal variability from the models by showing the range of trends from model ensembles (e.g., in DOE CWG Figure 5.3). The authors must discuss the potential effects of forcing biases on simulated warming trends. The incorrect claim that only models with the lowest ECS reproduce observed warming must be removed.

Page 31, 33, and page ix: Technical Comment

In terms of framing, the DOE CWG report portrays models as “overly sensitive,” which contributes to “exaggerated projections of future warming” (DOE CWG page ix). As already noted above, this characteristic applies to a subset of climate models and their projections have been downweighted in the IPCC AR6 assessment and other analyses (Hausfather et al., 2022). The DOE CWG report's statements on climate sensitivity must also be placed in the context of more comprehensive assessments of climate sensitivity that use many lines of evidence (e.g., Sherwood et al. 2020; Forster et al. 2021, Myers et al. 2021). In fact, recent research indicates

that analysis of satellite-era warming trends produces constraints on climate sensitivity and future climate projections that are biased low and overconfident (Armour et al. 2024). Moreover, the DOE CWG report's claim implies that raw climate model projections are the only source of data used to inform our expectations of future climate change. In reality, the IPCC report produces projections that are based on multiple lines of evidence, including climate models, assessed values of climate sensitivity, and observational constraints (Lee et al. 2021; Hausfather et al. 2022). In other words, inconsistencies between models and observations, as well as potential biases in model climate sensitivity, are explicitly taken into account in assessments of future climate change. These important considerations are entirely overlooked in the DOE report and should be corrected.

To correct these issues, the DOE CWG Report must note that individual analyses offer a poor constraint on climate sensitivity and future projections. The report must refer to the fact that in IPCC AR6, inconsistencies between models and observations and potential biases in model climate sensitivity values are taken into account in assessments of future climate change. Information about how well models simulate past warming, as well as other insights from observations and theory, are used to assess projections of global warming (see Cross-Section Box TS.1 in Arias et al. (2021)).

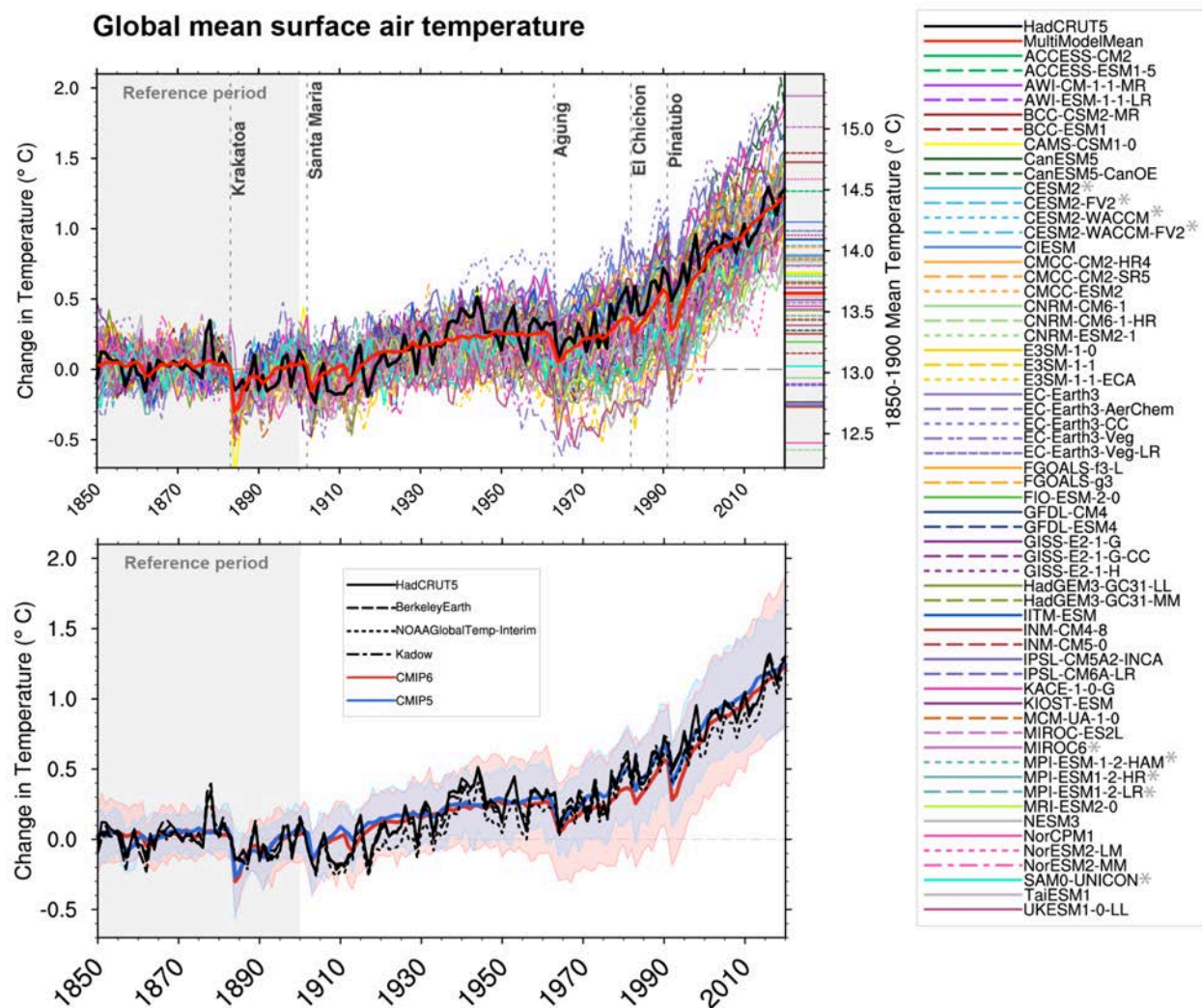


Figure 1 reproduced from IPCC AR6 Figure 3.4: Observed and simulated time series of the anomalies in annual and global mean surface air temperature (GSAT). All anomalies are differences from the 1850–1900 time-mean of each individual time series. The reference period 1850–1900 is indicated by grey shading. (a) Single simulations from CMIP6 models (thin lines) and the multi-model mean (thick red line). Observational data (thick black lines) are from the Met Office Hadley Centre/Climatic Research Unit dataset (HadCRUT5), and are blended surface temperature (2 m air temperature over land and sea surface temperature over the ocean). All models have been subsampled using the HadCRUT5 observational data mask. Vertical lines indicate large historical volcanic eruptions. CMIP6 models which are marked with an asterisk are either tuned to reproduce observed warming directly, or indirectly by tuning equilibrium climate sensitivity. Inset: GSAT for each model over the reference period, not masked to any observations. (b) Multi-model means of CMIP5 (blue line) and CMIP6 (red line) ensembles and associated 5th to 95th percentile ranges (shaded regions). Observational data are HadCRUT5, Berkeley Earth, National Oceanic and Atmospheric Administration NOAA GlobalTemp-Interim and [Kadow et al. \(2020\)](#). Masking was done as in (a). CMIP6 historical simulations were extended with SSP2-4.5 simulations for the period 2015–2020 and CMIP5 simulations were extended with RCP4.5 simulations for the period 2006–2020. All available ensemble members were used (see [Section 3.2](#)). The multi-model means and percentiles were calculated solely from simulations available for the whole time span (1850–2020). Figure is updated from [Bock et al. \(2020\)](#), their Figures 1 and 2. CC BY 4.0 <https://creativecommons.org/licenses/by/4.0/>. Further details on data sources and processing are available in the chapter data table (Table 3.SM.1).

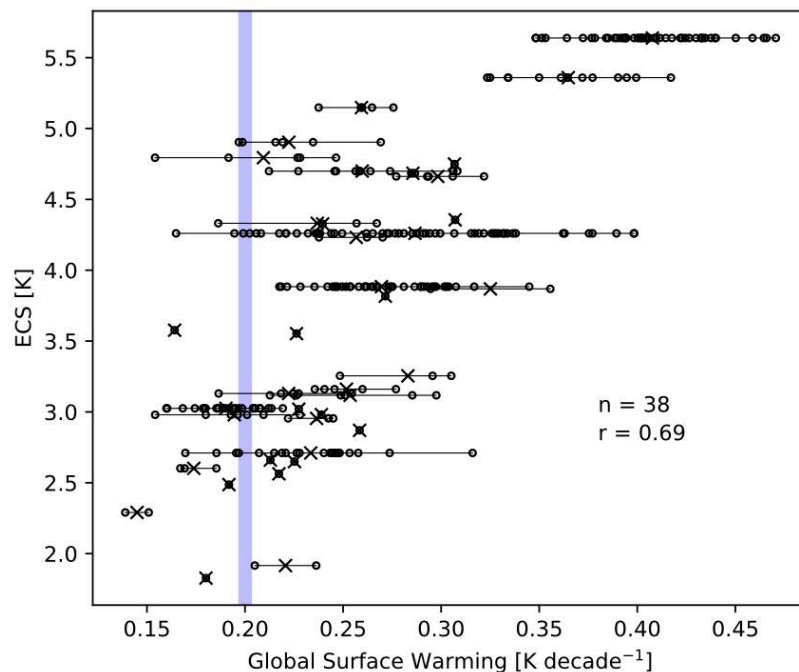


Figure 2: Global surface air temperature trends (1979–2024) in CMIP6 models (historical simulation over 1979–2014 and ssp370 over 2015–2024) versus model equilibrium climate sensitivity (ECS) values. Each open circle is an individual model member. When a model has multiple members, the ensemble mean is marked with an X and the range of trends is denoted with a horizontal black line. The range of observed surface trends from observations is denoted with the vertical blue line (across HadCRUT5, GISTEMPv4, BEST, and NOAA GlobalTempv6). The number of models (n) and correlation (r) across model ECS and model ensemble mean surface warming is noted in the figure. Note that the effects of a) “blending” sea surface and surface air temperatures and b) structural uncertainties from varied SST products were not accounted for in this comparison (Tokarska et al. 2020; Menemenlis et al. 2025).

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Section 5.3: Tropospheric Warming

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Summary: Comparisons between simulated and observed tropospheric temperature trends have received considerable scientific attention for decades. The heat transfer between the surface and the tropical troposphere is a critical component of the climate system and an important metric for evaluating climate models. While most model simulations exhibit more tropical and global tropospheric warming than observations, there are a number of factors that affect this model-observational comparison and it is premature to conclude that models are substantially deficient given the large uncertainties in observational estimates of atmospheric temperature trends, the role of internal variability, and the potential role of model forcing biases. The DOE CWG's discussion of this issue requires revision.

The following changes must be made to Section 5.3 in the DOE CWG document and to related statements in the executive summary and chapter summary:

- **Reference and discuss research that examines the role of humans in affecting tropospheric temperature trends.**
- **Include discussion of the large uncertainties associated with tropospheric temperature trend estimates and the potential role of observational biases in explaining model-observational differences in tropospheric warming rates. Internal dataset uncertainties and structural uncertainties should be included in graphics comparing trends from models and observations (DOE CWG Figure 5.4).**
- **Include representation of internal variability from the models by showing the range of trends from model ensembles (DOE CWG Figure 5.4). The potential effects of forcing biases on simulated warming trends must be discussed.**
- **Accurately reference to the IPCC AR6 statement that there is medium confidence that models “overestimate observed warming in the upper tropical troposphere over the 1979–2014 period by at least 0.1°C per decade”, contextualized with discussion of the impacts of internal variability, forcing biases, and observational uncertainties on model-observational trend differences.**

The authors assert that:

It has long been known that climate models on average overstate warming in the tropical troposphere. This region is an important test of climate models since this is where the signal of anthropogenic greenhouse warming emerges first and most strongly.

The suggestion in the DOE CWG Report that the tropical tropospheric temperature trend is a primary signal of anthropogenic climate change is an incorrect, strawman argument. In the tropics, the surface-troposphere system is strongly coupled by convection, which acts to maintain a “stable” vertical temperature structure. This strong coupling and moist thermodynamic processes (Stone and Carlson, 1979) mean that surface warming is accompanied by tropospheric warming regardless of whether surface warming is a result of anthropogenic or natural causes. Furthermore, the tropical troposphere is not “where the signal of anthropogenic greenhouse warming emerges first and most strongly.” The signal of human-caused CO₂ increases actually emerges first and most strongly in the mid- to upper stratosphere (Santer et al., 2023, 2025).

Attribution of climate trends generally leverages the spatial patterns of changes, and requires comparison of long-term trend patterns (signals) relative to the patterns of internal climate variability. Comprehensive detection and attribution analyses have demonstrated that the strength and pattern of simultaneous and sustained global-scale tropospheric warming and stratospheric cooling result from anthropogenic influence (Santer et al., 2017, 2023; Romanzini-Bezerra and Maycock 2024). Natural causes cannot produce this pattern.

To address this comment, the authors must correct the false statement that one metric, tropical tropospheric warming, is “is where the signal of anthropogenic greenhouse warming emerges first and most strongly.” The authors must refer to relevant studies regarding the human impact on the vertical structure of atmospheric temperature, from the lower troposphere to the upper stratosphere (Santer et al., 2023, 2025). Such studies find that anthropogenic influence has significantly affected atmospheric temperature trends, far beyond levels that could plausibly be explained by natural causes.

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The DOE CWG Report highlights that models “overstate warming in the tropical troposphere” and that:

The discrepancy was flagged as a serious inconsistency in the first U.S. Climate Change Science Program report (Karl et al. 2006) and has been mentioned in every IPCC report since, but the discrepancy has gotten worse over time, and the bias is now global.

While the DOE CWG Report focuses on model biases as the cause of model-observational differences, the US CCSP Report (Karl et al. 2006) actually points out that such model-observational discrepancies may arise from “errors that are common to all models, from

errors in the observational data sets, or from a combination of these factors. The second explanation is favored, but the issue is still open.” The CCSP Report’s emphasis on a role for observational biases was ignored in the DOE CWG Report. Evidence from the timescale-invariance of vertical amplification behavior and from complementary variables (like atmospheric moisture) suggests that observations may underestimate tropical tropospheric warming (Santer et al. 2005, 2021; Mears et al., 2007).

Observational biases and uncertainty continue to be a substantial concern for estimates of tropical and global tropospheric warming derived from satellite-based microwave sounders, which require the removal of significant non-climatic artifacts. Although uncertainty estimates for observations of tropospheric warming tend to be small (e.g., 0.05 K decade⁻¹ or less; Christy et al. 2003 and Mears et al. 2011), dataset updates frequently result in non-negligible trend updates that can sometimes be as large or larger than dataset uncertainty estimates (e.g., Mears and Wentz 2005; Christy and Spencer 2005; Mears et al. 2016; Zou et al. 2023). For example, a 2023 update applied to the National Oceanic and Atmospheric Administration Center for Satellite Applications and Research dataset (v4.1 to v5.0) resulted in a decrease in global (tropical) tropospheric temperature trends from 0.16 to 0.09 (0.23 to 0.14) K decade⁻¹ (Zou et al. 2023; Po-Chedley et al. 2023). Similarly, trend estimates from different research groups often differ significantly, even though the datasets are derived from the same raw data.

Radiosonde (weather balloon) and reanalysis-based observations likewise are subject to difficult to estimate and difficult to remove biases in their estimate of tropospheric warming (Titchner et al. 2009; Dee and Uppala 2009; Thorne et al. 2011; Haimberger et al. 2012; Sherwood et al. 2015). Homogenizing long-term radiosonde temperature datasets is challenging because of the relatively sparse, time-varying spatial coverage of records, systematic differences in the instrument types in different countries, changes in instrumentation as a function of time, and incomplete metadata. These challenges make it difficult to fully remove biases that affect temperature trends or to accurately quantify such biases (Titchner et al. 2009).

To address these issues, the DOE CWG Report must note that research, including assessment reports such as the CCSP Report, highlight a role for observational biases in explaining model-observational differences in tropospheric warming rates. The authors must also include discussion of the large uncertainties associated with tropospheric temperature trend estimates. Internal dataset uncertainties and structural uncertainties should be included in graphics comparing trends from models and observations (DOE CWG Figure 5.4). The authors should also discuss the potential for unaccounted for observational biases.

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The DOE CWG Report asserts that “Biases in tropospheric trends indicate model flaws in heat transfer processes that carry over to surface warming biases.” This statement ignores other possible contributors to differences in simulated and observed tropospheric warming. Aside from observational biases and uncertainty (discussed above), the DOE CWG Report also fails to

account for contributions of internal variability and forcing biases in explaining some of the differences in model-versus-observed warming rates (Mitchell et al. 2020; Fyfe et al. 2021; Po-Chedley et al. 2022; Casas et al. 2022). For example, several studies have pointed out that internal variability has likely reduced global and tropical tropospheric and surface warming over the satellite-era (Po-Chedley et al. 2022; Sweeney et al., 2023). Such multidecadal leaves an imprint on the pattern of surface warming; when climate models by chance exhibit a similar manifestation of internal variability to the real world, they produce a similar pattern of surface warming and trends that are in better accord with observations (Po-Chedley et al. 2021). The DOE CWG Report does not discuss the role of internal variability issues nor does it account for variability in its update to McKittrick and Christy (2020) (DOE CWG Figure 5.4). In this analysis, the authors only sample one simulation per model, even though the effect of internal variability can be substantial over this time period, enabling models with high climate sensitivity to produce simulations with trends near to or in the range of observations (Po-Chedley et al. 2021; Casas et al. 2022). Research also suggests that the forcings prescribed to models have substantial uncertainties (Fyfe et al. 2021; Holland et al. 2024). For example, discontinuities in model prescribed biomass burning aerosols has resulted in exaggerated warming in some models over recent decades (Fasullo et al. 2022; Po-Chedley et al. 2022). Studies have also shown that missing or incorrectly specified forcings can affect the consistency between simulated and observed tropospheric temperature trends (e.g., Santer et al., 2014, 2017b). Internal variability and forcing biases, in addition to climate sensitivity, must be accounted for when comparing simulated and observed tropospheric warming.

To correct these issues, the DOE CWG Report must include representation of internal variability from the models by showing the range of trends from model ensembles (DOE CWG Figure 5.4). The authors must discuss the potential effects of forcing biases on simulated warming trends.

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The DOE CWG Report concludes this section noting that, “despite the accumulation of evidence of excess model warming the IPCC assigns only medium confidence to the existence of a warming bias.” The suggestion is that the IPCC has understated the warming bias, but the actual statement in the IPCC Report is more specific: “we assess with medium confidence that CMIP5 and CMIP6 models continue to overestimate observed warming in the upper tropical troposphere over the 1979–2014 period by at least 0.1°C per decade, in part because of an overestimate of the tropical SST trend pattern over this period.” There is evidence that when internal variability, forcing, and observational biases are accounted for, CMIP models do not significantly exceed observed tropical or global tropospheric warming (particularly by such a large magnitude), especially for models with ECS values within the IPCC likely range of 2.5 to 4 K (Santer et al. 2021; Po-Chedley et al. 2022).

To address these issues, the DOE CWG Report accurately refer to the IPCC AR6 statement that there is medium confidence that models “overestimate observed warming in the upper tropical troposphere over the 1979–2014 period by at least 0.1°C per

decade". As noted above the authors must also discuss the impacts of internal variability, forcing biases, and observational uncertainties on the significance of model-observational trend differences.

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Section 5.4: Vertical Temperature Profile Mismatch

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Summary: Section 5.4 of the DOE CWG Report notes that the simulated and observed atmospheric temperature trends differ, which is likely true over some regions, altitude levels, and time periods. This issue was evaluated in the IPCC AR6 Report: “[W]e assess with medium confidence that CMIP5 and CMIP6 models continue to overestimate observed warming in the upper tropical troposphere over the 1979–2014 period by at least 0.1°C per decade, in part because of an overestimate of the tropical SST trend pattern over this period.” Although there is evidence that model biases play a role in shaping model-observation differences in the vertical profile of atmospheric temperature change, the influence of internal variability and the considerable structural uncertainty within the observational record preclude any firm conclusion with high confidence. Furthermore, it is not clear how a model bias in the profile of tropospheric temperature change would affect other aspects of the Earth system such as the climate sensitivity. The relative contributions of observational uncertainty, internal variability, errors in the prescribed model forcing, and model biases to the model-observation discrepancies are likewise unresolved. By omitting discussion of these uncertainties and overlooking evidence that does not align with its conclusions, the DOE CWG Report presents an incomplete and unbalanced account of the issue.

Particularly, the following changes must be made to Section 5.4 in the DOE CWG document:

- **Present peer-reviewed research that demonstrates that long-term tropospheric temperature trends are inconsistent with internal climate variability.**
- **The conclusion of Section 5.4 that the IPCC AR6 did not assess the atmosphere’s temperature profile and fundamental feedback processes is misleading and needs to be revised.** See for example IPCC AR6 Figure 3.10 on observed and simulated tropical mean temperature trends through the atmosphere.
- **Revise Figure 5.6 and related statements in the report to consider internal variability and to account for observational uncertainty. The potential role of model prescribed forcing biases should also be discussed.**
- **The simulated upper tropospheric temperature trends should be compared to GPS RO data, given the stability of GPS RO derived temperature observations.**

Page 36, Technical Comment

The authors note that observed trends from balloon-borne thermometers (radiosondes) appear to be consistent with natural forcings, though they omit that the figure cited (DOE CWG Figure 5.5) was adapted from Lott et al. (2013), which concluded that: “With increased confidence over previous studies, human influences (both greenhouse gas and other anthropogenic forcings) have been detected in spatiotemporal changes in free atmosphere temperature from 1961 to 2010, irrespective of whether the full atmospheric column (30–850 hPa) is examined or purely the troposphere, with stratospheric ozone depletion dominating the cooling that has been observed in the lower stratosphere.” The interpretation in the DOE CWG Report that observed atmospheric temperature trends are consistent with internal variability is also at odds with other comprehensive studies that demonstrate that the magnitude and structure of atmospheric warming is inconsistent with internal and natural climate variability (Santer et al. 2013; 2017b, 2023).

To correct this issue, the authors should reference and discuss peer-reviewed research that finds that long-term tropospheric temperature trends are inconsistent with internal and natural climate variability (e.g., Lott et al. 2013; Santer et al. 2013; 2017b).

Page 37, Technical Comment

The DOE CWG Report includes an update of the model-versus-observation vertical temperature trend profiles from Christy and McNider (2017). The updated figure uses reanalysis data as a stand-in for observations (the original analysis used radiosondes). From their figure (DOE CWG Figure 5.6) we see that there are substantial structural uncertainties in the data, especially in the upper troposphere. For instance, the JRA-3Q reanalysis overlaps with some model estimates of upper tropospheric warming while ERA5 tends to overlap with the models at some lower tropospheric levels. Aside from these structural uncertainties, it is important to recognize that reanalyses contain drifts and discontinuities that affect atmospheric temperature trends (Dee and Uppala. 2009; Hersbach et al. 2020).

Determining the vertical structure of tropical tropospheric temperature trends from radiosonde observations is also challenging because radiosonde stations are sparse, their trends are likely cold biased, and the bias magnitude cannot be accurately determined (e.g., Sherwood et al. 2005; Randel and Wu 2006; Titchner et al. 2009). Discontinuities in the radiosonde data may propagate into reanalysis trends (Zhou et al., 2021), which ingests available data into a model to produce a physically coherent gridded product. Furthermore, the amplification ratio (e.g., the ratio of 700 mb and 250 mb warming) is also dataset dependent and has spread among the CMIP6 models (Keil et al., 2021).

In part due to such significant observational uncertainties, the consistency of modeled-versus-observed amplification is dependent on the amplification metric, dataset (and dataset version), and time period considered (Fu et al. 2011; Po-Chedley et al. 2012; Seidel et al. 2012; Santer et al. 2017a; Keil et al. 2021; Zhou et al., 2021). It is likely that differences

between models and observations are at least partially due to observational biases in upper air observations (Po-Chedley et al. 2015; Sherwood et al. 2015).

Independent analyses of high quality temperature datasets derived from global position system (GPS) radio occultation (RO) measurements show upper tropospheric warming and vertical amplification that is consistent with climate models (Fig. 1; Steiner et al. 2011; 2020; Vergados et al. 2021; Ladstädter et al. 2023). Other independent lines of evidence that suggest the tropics follow a near moist adiabatic profile come from thermal wind balance (Allen and Sherwood 2008; Sherwood et al. 2015) and from Johnson and Xie (2010), who argue from the distribution of convection in the tropics that there is no systematic trend toward large-scale destabilization of the temperature profile. Furthermore, underappreciated structural uncertainty in surface temperature trends likely support a wider range of vertical amplification values (Menemenlis et al. 2025) than has been recognized in previous analyses. As in Section 5.3, when comparing models and observations, the DOE CWG Report fails to account for observational biases and uncertainty.

To correct this issue, the DOE CWG Report must include information about observational uncertainty when comparing models and observations and include this information in figures. The DOE CWG Report must also compare climate models to upper tropospheric temperature trends derived from GPS RO data, given the stability of GPS RO derived temperature observations.

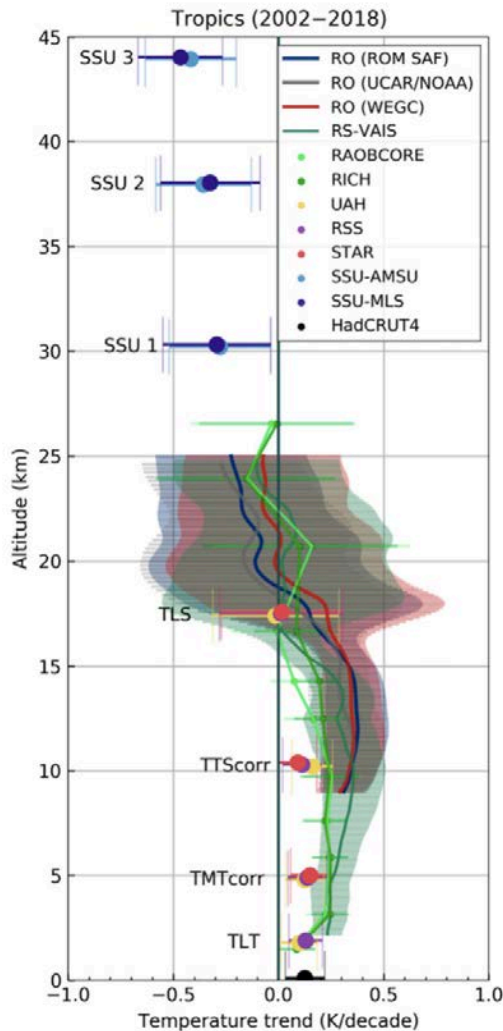


Fig. 1. Upper-air temperature trends 2002–18 from different observations for the tropics (20°S–20°N). Layer-average temperature trends are shown for MSU-AMSU (RSS, STAR, UAH) and for merged SSU records. Vertically resolved trends are shown for radiosonde records (RS-VAIS, RICH, RAOBCORE) and for RO records (ROM SAF, UCAR/NOAA, WEGC). Surface temperature trends from HadCRUT4 are also indicated. Trends were computed with multiple linear regression. The uncertainty of trends is indicated at the 95% confidence level. Reproduced from Steiner et al. (2020).

Page 37 and 38, Technical Comment

The statement, “The atmosphere’s temperature profile is a case where models are not merely uncertain but also show a common warming bias relative to observations. This suggests that they misrepresent certain fundamental feedback processes. The IPCC AR6 did not assess this issue,” is incorrect. Models and observations were compared in Chapter 3.3.1.2.1 of the IPCC AR6 Report (Eyring et al. 2021). The report shows that tropical atmospheric temperature trends from radiosonde observations and models are in agreement over 1979 to 1997, but diverge over 1998 to 2014 with observations showing weaker tropospheric warming compared to climate models. This latter time period corresponds to the so-called “hiatus” period in which internal

climate variability appears to have reduced surface warming (Dai et al. 2015). The pattern of warming, which can be modulated substantially by internal variability, affects surface warming in regions of deep atmospheric convection which is an important control on vertical amplification behavior (Flannaghan et al. 2014; Tuel, 2019; Po-Chedley et al. 2021). When models are forced to match the spatio-temporal pattern of real-world surface variability and trends via prescribed sea surface temperatures, the simulated vertical profile of atmospheric temperature trends over this sub-period and the full satellite era are in better accord with observations (Mitchell et al. 2020; Po-Chedley et al., 2021). This suggests that some of this model-observational discrepancy may be due to internal variability. As noted in the Mitchell et al. (2020) study:

As for the modeled tropospheric trends, however, the discrepancy with observations is much larger after 1998. We suspect that one cause of this discrepancy is related to the fact that the 1998-2014 period corresponds to the occurrence of the so called ‘global warming hiatus’ (see Fyfe *et al* [2016](#), for a recent update of this debate). If the hiatus is indeed related to an increased heat uptake by the oceans, as suggested by some studies (Meehl *et al* [2011](#), Meehl *et al* [2014](#)), it cannot be considered an externally forced process: therefore, one would not expect it to be captured in the models over the same time period. Another contributing factor is that 1997/1998 had one of the largest El Niño events on record, which, given the short period the trend is calculated over, becomes important. Indeed, if the analysis is repeated for the 1999-2014 period (i.e. missing the large El Niño year), the tropospheric observational trends are higher, and in better agreement with the coupled model estimates (figure S3). Be that as it may, we note here for the record that from 1998 to 2014, the CMIP5 models warm, on average 4 to 5 times faster than the observations, and in one model the warming is 10 times larger than the observations.

In addition to the effect of internal variability, biases in the forcings prescribed to models may also affect model-observational agreement (as discussed in the comment on Section 5.3 of the DOE CWG Report). The relative role of observational biases, model biases, internal variability, and model forcing biases in model-observation differences in the vertical profile of atmospheric temperature trends is not known. Discussion of the myriad of factors that affect the evaluation of the vertical structure of simulated temperature trends is omitted from the DOE CWG Report.

To correct this issue:

- **The DOE CWG should remove the assertion that the IPCC Report did not discuss this issue.**
- **The authors should include discussion of the potential role of internal variability and potential model forcing biases in explaining model-versus-observed warming differences.**
- **The DOE CWG Report should include the spread in trends across large model ensembles to account for the effects of internal climate variability (e.g., in DOE CWG Figure 5.6).**

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Section 5.5: Stratospheric Cooling

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Summary: This section of the DOE CWG Report inaccurately and incompletely refers to published literature, makes inaccurate claims, and ignores the strong observed and simulated cooling of the middle and upper stratosphere. The DOE CWG Report asserts that observed lower stratospheric warming since the year 2000 is at odds with model simulations. This claim is incorrect.

The following changes must be made to Section 5.5 of the DOE CWG Report:

- **The authors must describe the strong middle and upper stratospheric cooling and that this cooling strongly improves the detectability of anthropogenic influence on climate. The authors must not compare vertical fingerprinting results over the full satellite era to trends in individual atmospheric layers in sub-selected time intervals.**
- **The authors should include the omitted text in their block quotation of Philipona et al. 2018.**
- **The authors must accurately describe atmospheric temperature change in different layers. The middle and upper stratosphere cool throughout the satellite era (1979 to present) and the lower stratosphere cools over 1979 to 2000 and then experiences muted trends after the year 2000.**

Page 38, Technical Comment

In framing this section of the DOE CWG Report, it is stated that the expected “fingerprint” of anthropogenic climate change is tropospheric warming and stratospheric cooling. While this is true for fingerprints derived over the full satellite era, the exact details of the vertical fingerprint pattern would vary in the *lower* stratosphere if other time periods were used. This is for the reasons stated in the DOE CWG Report: that stratospheric temperature change is “influenced by ozone depletion and recovery.”

It is important to note that because of the vertical distribution of ozone, the effects of ozone concentration changes are strongest in the *lower* stratosphere; in the middle and upper stratosphere, cooling is expected both in the ozone depletion and ozone recovery period. This is exactly what is observed: stratospheric cooling in the middle and upper stratosphere over the full observed time period as well as over the ozone depletion and recovery periods (see trends and time series in SSU2 and SSU3 in Santer et al. 2023, 2025; Maycock et al. 2018). Regardless, anthropogenic influence on atmospheric temperature is detectable over the satellite

era and is substantially stronger when information from the middle and upper stratosphere is included (Santer et al. 2023).

To correct this issue, the authors must not compare vertical fingerprinting results over the full satellite era to trends in individual atmospheric layers in sub-selected time intervals. The authors must describe the strong observed middle and upper stratospheric cooling and that this cooling strongly improves the detectability of anthropogenic influence on climate.

Page 38, Technical Comment

The study cited by the DOE CWG Report in their discussion of lower stratospheric temperature change (Philipona et al. 2018) derived lower stratospheric warming from sparse radiosonde observations, but also showed that satellite observations over the same post-2000 time period show weak cooling, consistent with observational results in other studies (Santer et al. 2021). Regardless of whether the observed trend is weakly positive or negative, the key point here is that model-simulated lower stratospheric temperature trends after the year 2000 are not at odds with observational results (Santer et al. 2021; 2023). The model post-2000 trends encompass both cooling and warming, consistent with a weak forced trend arising from the offsetting effects of warming from ozone recovery and CO₂-induced lower stratospheric cooling. The DOE CWG Report is incorrect in stating that “the stratosphere has shown some warming since [2000], contrary to model projections,” since the sign of the observed trend is not well constrained and because model simulations produce both positive and negative lower stratospheric temperature trends for the post-2000 period.

Page 39, Reference Comment

In the block quote referencing Philipona et al. (2018), the authors incorrectly omit part of the last sentence, which explains the observed behavior (bolded here): “Trend estimates are somewhat sensitive to homogeneity assessment choices, but all investigated radiosonde data sets suggest a change from late twentieth century cooling to early 21st century warming in the lower stratosphere, **which is consistent with a reversal from ozone depletion to recovery from the effects of ozone-depleting substances.**”

To correct this error, the authors must include the full quotation.

Page 39, Technical Comment

The DOE CWG Report makes a stand-alone statement that “Santer et al. (2023) use updated data to show that a cooling trend has not re-emerged in the lower stratosphere.” This statement is incorrect. Santer et al. (2023) show that expected stratospheric cooling in the middle and upper stratosphere is evident in both climate models and observations, both before and after 2000. While Santer et al. (2023) do not show the observed time evolution of lower stratospheric temperature trends over different time periods, that information was provided in an earlier paper

(Santer et al. 2021, their Fig. 4). Santer et al. (2021) showed that in both the observations and model simulations, trends in lower stratospheric temperature differ markedly between the pre-2000 ozone depletion and post-2000 ozone recovery periods. Cooling is large over the depletion period and muted over the recovery period. This common behavior in simulations and observations is due to the competing effects of ozone concentration changes and increases in CO₂. The DOE Report is silent on the fact that observational evidence of strong, persistent middle and upper stratospheric cooling and tropospheric warming is consistent with model simulations and with a “fingerprint” of anthropogenic influence (Santer et al. 2023, 2025; Maycock et al. 2018).

To correct this issue, the authors must provide an accurate description of stratospheric temperature change by layer: In the lower stratosphere, observed stratospheric cooling over 1979 - 2000 is followed by muted trends after the year 2000. In the middle and upper stratosphere, strong cooling is evident throughout the satellite era (1979 to present). In both cases, observed stratospheric changes are within the range of model results given observational uncertainties.

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Comments on Section 5.6 “Snow cover mismatch”

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The DOE report in Section 5.6 makes erroneous and misleading claims about Northern Hemisphere and West Pacific snow extent and snow melt trends.

1. Suggestion that climate models have failed to simulate observed trends in wintertime Northern Hemisphere snow cover, but use only one observational product and do not properly convey that it has known trend biases.

2. Ignore more robust snow cover declines during other times of the year that are also important for water resources.

3. Incorrect suggestions that there has been minimal snowpack changes in Pacific states.

To correct these technical flaws, the following changes must be made in the DOE CWG report document:

- 1) Update the text to correctly cite the relevant scientific literature and ensure it is known that snow cover extent (SCE) is declining in the N. Hemisphere in most months, and the balance of evidence suggests that this is true in all months.
- 2) Discuss the role of boreal spring declines in snow cover and decreases in Western US snowpack for water resources.
- 3) Remove erroneous statements about trends in specific states or the hemisphere as a whole.

The DOE report is focused heavily on the ability of climate models to reproduce certain observations and/or observed sensitivities (for instance, climate variables such as snow cover and/or water equivalent to temperature). Section 5.6 of the DOE CWG report has two main points: first, highlighting observational evidence indicating the lack of decline in Northern Hemisphere snow cover extent in contrast to decreasing trends simulated by climate models, and second, observational evidence for changes in winter snow accumulation in the coastal Western U.S. We address here the observational evidence in these two areas, which we believe has been

inadequately addressed in the report. We also stress that no single thermal or physical indicator is a sufficient metric for characterizing the response to a warming climate.

Northern Hemisphere Snow Cover Extent (SCE):

The report notes that the Rutgers SCE product for the Northern Hemisphere shows no statistically significant trend in winter, whereas climate models generally predict declines. We first note that the observational product discussed in the DOE report (the Rutgers/NOAA Climate Data Record) is not robust with respect to NH winter trends and disagrees with many other observational datasets (Figure 1 below. See Brown and Derksen, 2013; Hori et al. 2017; Mudryk et al., 2017; Urraca and Gobron, 2023). Mudryk et al. (2020) analyzed six observation-based snow extent products for the period 1981–2018 and showed that trends in NH SCE are negative in all months and strongly linked to surface temperature. Other important metrics such as snow mass have also declined, especially over North America (Pulliainen et al., 2020; Gottlieb and Mankin, 2024). Although the authors of the DOE CWG report acknowledge the observational uncertainty, this is a known issue that is simply brushed aside to conclude, “Further work to reconcile conflicting trends in observational data sets is required.” This presents a misleading balance of evidence in the overarching goal discussing the manner in which “greenhouse gas emissions have affected, or will affect, the Nation’s climate, extreme weather events, and selected metrics of societal well-being” (their first sentence of the Executive summary).

Furthermore, the climatology of SCE in winter has improved in CMIP6 compared to CMIP5, and despite the structural uncertainties in the observations, the models appear to be consistent with the observed trends (Mudryk et al. 2020).

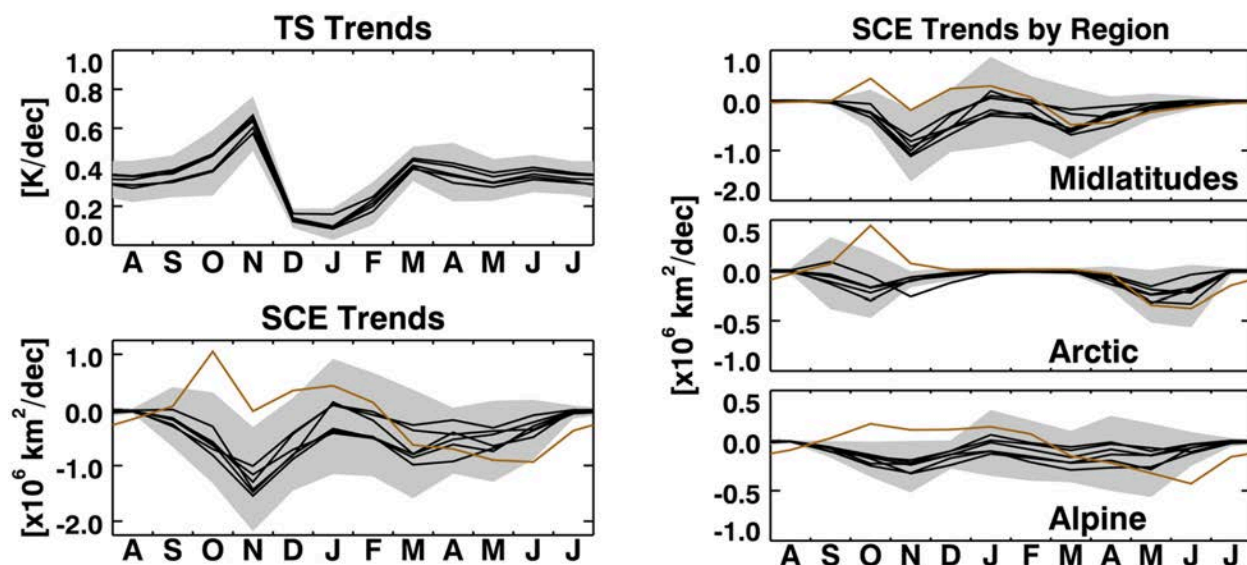


Figure 1. Adopted from Mudryk et al. (2017). Estimates of observed monthly Northern Hemisphere (NH) (top left) surface temperature (TS) trends from 1981-2010 and (bottom left)

snow cover extent (SCE) trends. SCE trends are also shown for (right column) three subregions. Trends calculated from the NOAA Climate Data Record (NCDR) are shown in brown.

The strong downward trends in SCE in spring are also very important to ecosystems, hydrology, water security, and agriculture (Mankin et al., 2015; Qin et al., 2020). A substantial fraction of the world's population relies on seasonal melt (Barnett et al., 2005). From a physical climate perspective, the snow trends in spring are important simply because downward solar radiation is much higher in spring than winter, hence the contrast in albedo (snow cover vs snow free) makes more difference to net radiation at the land surface (Déry and Brown, 2007), and to related variables like evapotranspiration and photosynthesis.

Spring snowpack declines have been observed in many mid-latitude basins and these declines have been attributed to human influence (Paik and Min, 2020; Gottlieb and Mankin, 2024). For example, Milly and Dunne (2020) showed that ongoing downward trends (of roughly 10% per degree C) in the annual discharge of the Colorado River are traceable to changes in spring SCE in the river's headwater regions that lead to increased net radiation and evapotranspiration, and decreased river discharge. The Colorado River is the major water supply source for over 40 million people in the U.S, Southwest, and several million acres of irrigated agriculture.

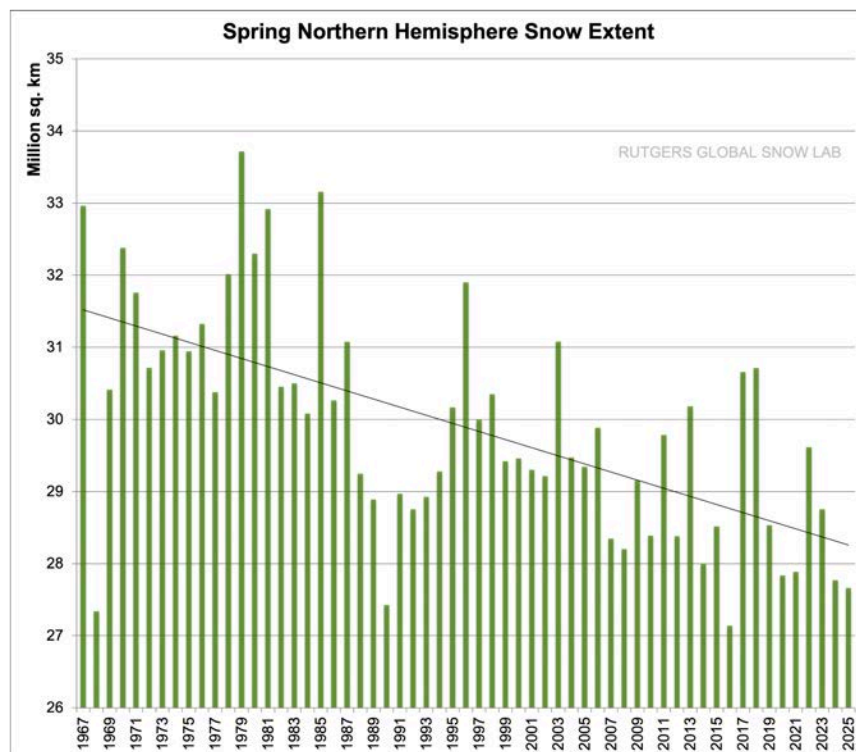


Figure 2: Spring trends in N. Hemisphere SCE from https://climate.rutgers.edu/snowcover/chart_seasonal.php?ui_set=nhland&ui_season=2 (accessed Aug 18, 2025)

We note that the authors of the DOE CWG report chose to only report on wintertime snow trends and did not show data from other seasons. Even the Rutgers data they cite show substantial springtime snow cover declines (Figure 2 below) and these anomalies should be included in the broader context of a changing cryosphere.

Pacific Coast snow water storage: Since the work of Church on Mt. Rose and elsewhere in the West in the 1920s and 1930s, hydrologists have recognized the importance of snow water equivalent (SWE) as an indicator of spring and summer streamflow from snow-dominated watersheds in the Western U.S. By the 1940s, measurements of SWE (typically using the Mt. Rose snow sampler, which remains the standard for manual observations of SWE) were being used routinely to forecast seasonal streamflow in the major rivers of the Western U.S. for water supply purposes. That function is shared (depending on location and purpose of the forecasts) by the USDA Natural Resources Conservation Service and the National Weather Service River Forecast Centers.

Numerous papers (e.g, Mote et al. 2005, Luce et al. 2014, Mote et al. 2018; Musselman et al., 2021; Hale et al., 2023) have documented declines in western snowpack, especially using the most common observation date of April 1, and many papers (those just listed, plus Pierce et al. 2008) have statistically linked these declines to warming. The first analysis of trends in snowpack in both the western US and southwestern Canada analyzed the SWE observation archive from NRCS, California's Department of Water Resources, as well as Canadian agencies (suitably pre-processed for error removal) for long-term trends (Mote et al., 2005). They found pervasive downward trends in SWE for the period 1950-97 which were most pronounced at locations with relatively warm (close to 0°C) average winter temperatures, and corroborated these results with an independent calculation using a hydrology model. A subsequent paper (Mote et al., 2018) updated the observational records through 2016, and reached essentially the same conclusion using a range of starting dates for analysis, and in addition showed that the declines were observed in every month.

Additional, independent evidence for declines in spring snowpack are provided by streamflow observations. Stewart et al. (2005) independently analyzed streamflow at unregulated stream gauges across the West, and found that for watersheds where snow contributed much of the annual runoff, there had been persistent shifts in runoff earlier in the year (more in winter, less in spring and summer) over a period of record comparable to that used by Mote et al. (2005). Stewart et al. also analyzed streamflow timing in unregulated gauges with minimal snow effect, and found that they did not exhibit the same timing shifts. Taken together, these two studies offer strong evidence that ongoing warming across the Western U.S. (Harpold et al., 2017) has led to declining spring snow water storage and associated shifts in seasonal runoff timing.

These documented changes are critical to water managers, as manmade reservoir storage (which is mostly intended to shift water availability from spring and early summer to the period of maximum water demand later in the year) has historically been augmented by natural storage in

the snowpack (SWE being the key indicator). That natural storage is being eroded as indicated by declining spring SWE.

The report ignores all of the above work. It is worth noting that the reality of warming-driven snow droughts is widely accepted by water managers in the US, who are therefore not well served by the very incomplete picture presented in section 5.6. The treatment of western snowpack changes rests solely on a less relevant set of results with a different variable. It states “A comprehensive reconstruction of snowfall for the main source regions (Cascades and Sierra Nevada Mountains) indicates no significant trends in annual totals since the late 19th century (Christy 2022)”. Presumably the authors meant to include a 2012 paper by Christy which covers California (the 2022 paper uses the same methods as 2012 applied to Washington and Oregon).

Much more important however is that both papers are based on snowfall measurements obtained from records at stations where manual measurements (essentially with rulers) of snow depth are made. The variable examined by the authors is snowfall accumulated each day over the winter and spring. This is not SWE, and in fact is a poor indicator of SWE (which as indicated above is a widely used index of runoff) because a) the stations used in both papers are heavily biased towards low elevations, and are poor indicators of conditions at higher elevations where SWE is largest; and b) because they are at low, relatively warm elevations, some stations transition from snow covered to bare throughout the winter, hence the total accumulated winter snow depth is a poor indicator of spring conditions.

Notably, the authors of the Christy reference cited in the report acknowledge that SWE is a better indicator of snowpack water availability. Taken together, it’s not surprising that the two Christy papers found an absence of trends for both California (2012) and Washington and Oregon (2022), but what of relevance is to be taken from those results relevant to the DOE report isn’t clear. The alternative papers cited above in this comment, which document considerable declines in mountain SWE, suggest there are significant vulnerabilities with respect to climate warming, snowpack, and water resources in the Western US which warrant acknowledgement in the DOE report.

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Section 5.7: Hemispheric symmetry of the planetary albedo

edited by A.E. Dessler, Texas A&M University

Section 5.7 of the DOE CWG report explains that Earth's Northern and Southern Hemispheres have nearly identical albedos, despite big land-ocean differences, likely due to cloud compensation in the south. Observations show this symmetry within $\sim 0.1 \text{ W/m}^2$, but most CMIP6 models fail to reproduce it, with errors up to 5 W/m^2 . This mismatch suggests problems with cloud feedbacks and reduces confidence in some future climate projections

This is a technical comment on Section 5.7 (p. 41-42)

The authors of the review rightly call out Earth's Energy budget (EEB) as being an important measure of climate as Earth's Energy Imbalance (EEI) is among the fundamental drivers of climate change. Fundamental insights have been provided into EEB by the Clouds and the Earth's Radiant Energy System (CERES) project since 2000. The authors are also quick to point out an intriguing aspect of EEB in CERES is the symmetry of albedo between hemispheres, as discussed in Stephens et al. (2015).

The Earth represents an extraordinarily complex system with extensive observational datasets. When analyzing such vast amounts of data, it is inevitable that patterns will emerge that appear anomalous or that current models struggle to reproduce. However, the mere existence of such patterns does not automatically establish their fundamental importance to climate science. Without clear mechanistic understanding, demonstrated persistence across extended timescales, or quantifiable impacts on climate-relevant parameters, attributing significance to these observations requires substantial additional evidence and analysis.

That is the case here: Beyond the mere existence of the symmetry, any broader significance is unproven. We don't know if the symmetry holds across longer time periods nor do we know whether a few W/m^2 error (out of $O(1,000) \text{ W/m}^2$ of solar insolation) will translate into errors in parameters we care about (see Stephens et al. 2022 and Hakuba et al. 2024). We don't know if it is indicative of a feedback nor do we know whether, if so, if it might reduce or exacerbate climate change. For these and various other reasons (see below), there is little justification for viewing the symmetry as a fundamental parameter of our climate system.

The DOE CWG report nonetheless treats this symmetry as a fundamental climate parameter despite the lack of supporting evidence. This assumption is baseless and a major problem with this section.

To correct this error, the following additions must be made in the DOE CWG document:

- An acknowledgment should be added that the observed symmetry is not a key parameter in our climate system.
- A discussion of the peer-reviewed literature should be included that discusses how the albedo symmetry connects to changes in climate sensitivity, cloud feedback, or future warming.

Further, it is a major error of omission to focus on the albedo symmetry in the CERES data rather than the more important quantity, EEI, which is increasing over time and with a rate that is stronger than simulated by most climate models. (Raghuraman et al. 2021). This measurement by CERES reveals increases in the accumulation of heat by the climate system that are likely to result in increasingly rapid global warming. It also suggests stronger integrated ocean warming, ice sheet melt, and sea level rise, and potentially stronger feedbacks than are simulated by modern climate models.

To correct this error, the following additions must be made in the DOE CWG document:

- Incorporation of a broader discussion on EEI, its connections to ocean warming, ice sheet melt, and sea level rise.
- Addition of a discussion of uncertainty in feedbacks and the approaches necessary for better constraining them, including prolonged monitoring of EEI and the reservoirs of heat in the Earth system through projects such as CERES.

Despite citing their work in Fig 5.8, the authors selectively ignore key statements made by Rugenstein and Hakuba (2023) based on their analysis including that the albedo symmetry is a function of the current climate state (i.e. not intrinsic), and that albedo will likely evolve to be asymmetric in coming decades. Also, the authors show in their Fig. 5.8, yet fail to mention in the text, that some models do simulate a symmetry in albedo between the hemispheres within measurement uncertainties - including the high sensitivity E3SM1.0. They further fail to mention that these models do not systematically differ in their projections from models that fail to capture the symmetry. This observation suggests, consistent with the findings of Rugenstein and Hakuba (2023) that the fidelity of future projections does not depend on a model's ability to simulate the symmetry and that is not indicative of a mechanism of climate stability.

To correct this error, the following additions must be made in the DOE CWG document:

- an acknowledgment that our best understanding of the asymmetry is that it is likely not constant but variable in time
- an acknowledgment that some models do simulate the observed symmetry in albedo between hemispheres, including some with very high climate sensitivity
- an acknowledgment that the ability of a climate model to reproduce the observed symmetry is not indicative of the climate projections it generates

The mechanisms that would underpin any “cloud feedback processes” suggested by the authors would rely on fields governed by temperature and moisture such as tropospheric stability, upper-level dryness, boundary layer inversion strength and related fields. Yet temperature and moisture are governed by the total radiative flux, not the shortwave portion of the spectrum. Longwave fluxes and hence net fluxes do not exhibit hemispheric symmetry. This calls into question the existence of any regulation mechanism.

To correct this error, the following changes must be made in the DOE CWG document:

- An acknowledgement that confidence in inferring errors in projected climate as a result of a given model bias require, at a minimum, a robust identification of model biases, a demonstration that the degree of bias in a given model is tied to the character of its projections, and a mechanism that connects the present-day bias to simulated climate feedbacks.

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Response to section 5.8

A.E. Dessler, Texas A&M University

This section is a **technical comment** on Section 5.8 of the DOE CWG report, beginning on **page 42**, and Figure 5.9, which is on **page 43**.

In this section of the DOE report, the authors write: “One of the largest discrepancies between models and observations is in the U.S. Corn Belt, a region of particular importance to global food production. Figure 5.9 shows the warming trends for summertime (June, July, August) for the 12-state Corn Belt (IN, IA, IL, ND, SD, MO, MN, WI, MI, OH, KS, NE) during 1973-2022. All 36 climate models (red) warm far too rapidly compared to observations (blue).” This is part of an overarching argument that models are not good enough to use for prediction of the future climate.

As described below, this argument relies on sloppy data analysis and cherry picking to reach a conclusion that analysis of the full data record does not support.

Response:

First, climate models have an admirable track record of predicting the *global average* temperature (Hausfather et al., 2020). While the global average temperature is well constrained by planetary energy balance, how that warming is distributed around the planet can vary greatly due to what we refer to as *unforced variability*. This phenomenon is similar to the randomness we observe in weather patterns, but are driven by the ocean circulation on much longer time scales, such as the El Niño/La Niña oscillations.

As an example, you can take a climate model and run it many times, with identical emissions of carbon dioxide, but with each run starting with a slightly different state of the climate system. For these runs, the global average temperature change is similar, but how the warming is distributed varies greatly:

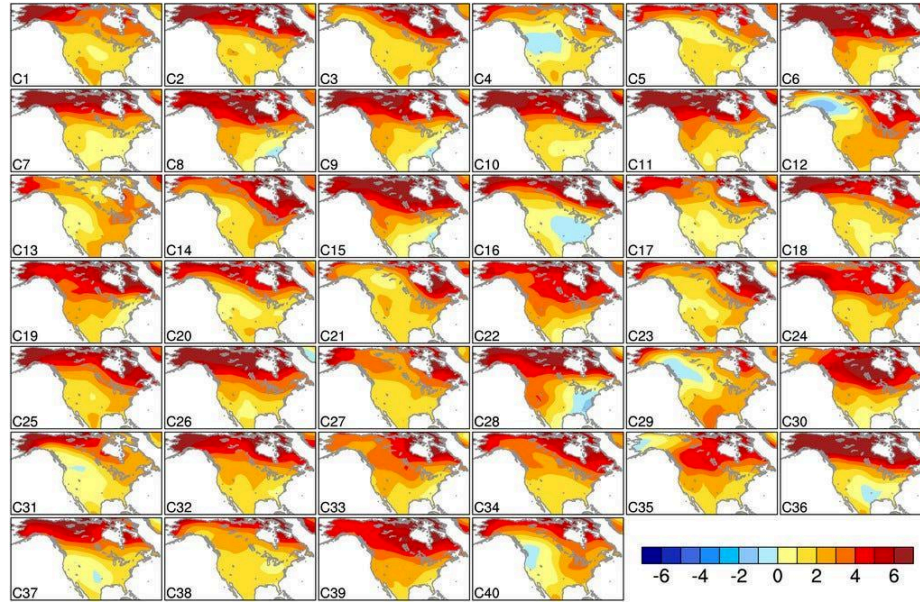


Figure 1. Winter surface temperature trends [2010–60; $^{\circ}\text{C} (51 \text{ yr})^{-1}$] from each of the 40 CCSM3 ensemble members. From Fig. 1 of Deser et al. (2014)

In some of the ensemble members (e.g., C16, C28), the Southeast U.S. cools between 2010 and 2060, while in most others it warms. In some members (e.g., C4, C29, C40), the Pacific Northwest cools, while in most others it warms.

This has important implications for the plot in Sect. 5.8. To see this, let's take a single model, in this case, ACCESS-ESM1-5, which has an ensemble of 40 historical runs in the CMIP6 archive. Each run has different initial conditions, so each run of the model will have a different pattern of warming and cooling, just like we see in the plot above.

Summertime central U.S. warming in this one model ensemble looks like this:

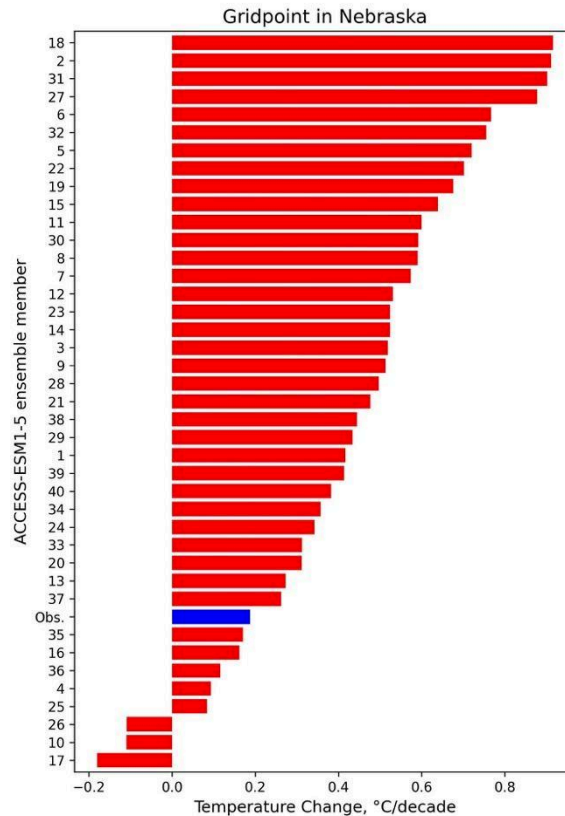


Figure 2. Warming of a grid point in Nebraska between 1970 and 2014 from 40 runs of a single model (ACCESS-ESM1-5) with different initial conditions. Model results are red, the observation is in blue.

This shows the importance of unforced variability: 20% of the runs show smaller warming than observations, and 8% show *cooling*. At the other end, there are ensemble members that show five times the observed warming. This spread is due entirely to different initial conditions, so this is an example of chaos in a strongly non-linear system.

So is the model in Fig. 2 (ACCESS-ESM1-5) overestimating warming in this region or not? *There's no way to know*. If you pick ensemble member 17, the model is underestimating the warming. If you pick ensemble member 35, the model is doing a fantastic job, while ensemble member 18 is overestimating the warming.

Without figuring out which of these ensemble members has unforced variability matching the unforced variability in the real world (this is really hard, by the way), the only correct conclusion is that the observed warming falls within the envelope of warming predicted by this model, so you **cannot** conclude that the ACCESS-ESM1-5 is overestimating warming.

This also means that Figure 5.9 of the DOE report, which shows one value for this model, ~0.6°C, is scientifically inaccurate.

To construct Fig. 5.9 of the report, I'm guessing a random run of each model was selected. So let's remake the plot, but using the ensemble member from each model that shows the *lowest warming* in this region. I limit myself to models that have ensembles with at least five runs in the CMIP6 archive.

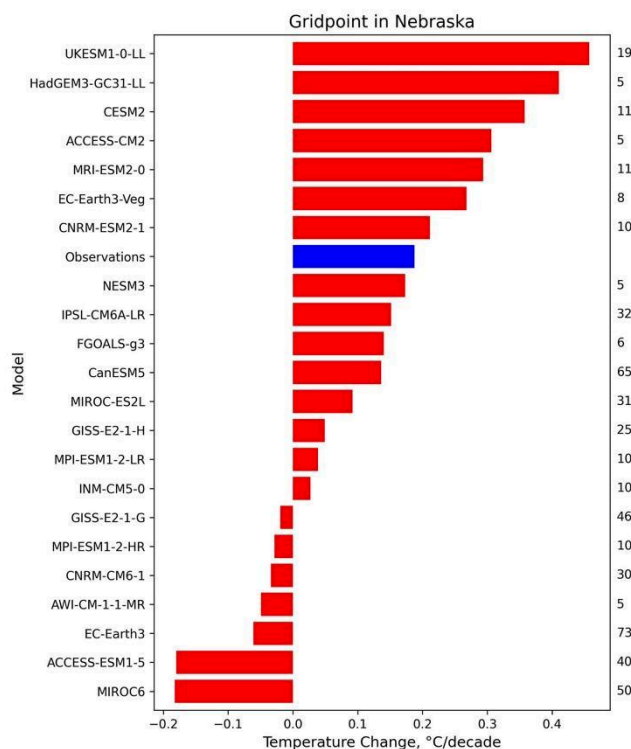


Figure 3. Warming of a grid point in Nebraska between 1970 and 2014 from the ensemble member of each model with the lowest warming in this region. Model results are red, the observation is in blue. The number of ensemble members for each model is displayed off the right edge of the plot.

Figure 3 shows that the results of the ACCESS-ESM1-5 are generalizable. Two thirds of the CMIP6 models produce warming lower than observations in their ensembles. Again, this doesn't prove the models are right, but it does say that **naive comparisons that ignore unforced variability, like Fig. 5.9 in the DOE report, are biased and unreliable.**

What's a better way to do the calculation?

While unforced variability can impact any single location, if you look globally, the impact of it cancels out — regions that are cooled by unforced variability are cancelled by other regions that are warmed. Thus, the right way to do this calculation is globally.

To that end, I've taken a single run of each of 45 CMIP6 historical model runs and the observations and calculated this same change in summertime surface temperature, but at each point on the globe.

If the CMIP6 models are accurately simulating the climate, I would expect that areas where the model average is warming faster than the observations would be about equal to the area where the model average is warming slower.

If I screen models by eliminating those (Hausfather et al., 2022) that have equilibrium climate sensitivity that's out of the accepted range (2°C-4°C), then the average warming of the models exceeds observations over 48% of the area of the Earth, with observed warming exceeding the models over the other 52%. [If I don't remove the too-hot models, then 63% of the globe shows models warming more than observations]

These results are exactly what we would expect if the models are accurately simulating the climate system.

What's really going on?

Fig. 4 shows the spatial pattern of the difference between the average of the screened model ensemble and the observations. Red colors indicate where the average model warming is faster than observations while blue areas show that models are warming slower. As mentioned above, 52% of the area of the globe is blue, indicating places where the models are warming slower than observations.

The box over North America shows the region that the DOE plot focuses on. It's clear that the region that was selected in the DOE plot is *the place in the Northern Hemisphere where models look the absolute worst*. This constitutes a textbook case of cherry picking — the practice of selectively extracting a narrow subset of data that contradicts the broader dataset to support a predetermined conclusion.

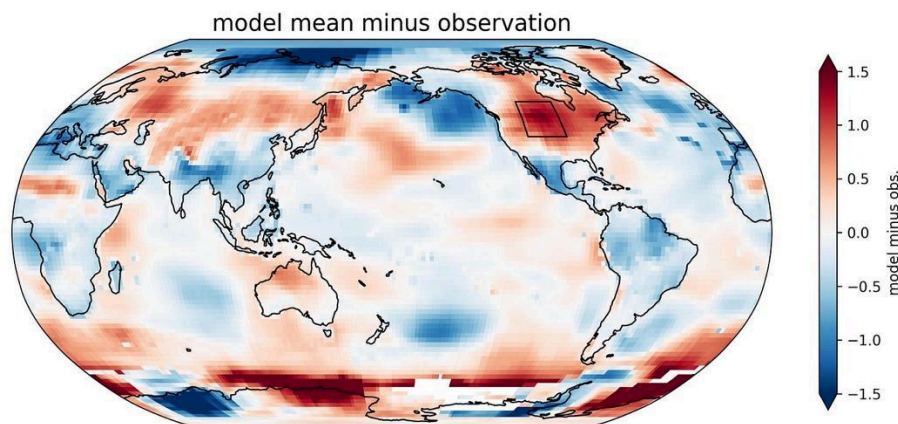


Figure 4. Average warming in the screened models minus observed warming, 1970-2023. the box indicates the region that Fig. 5.9 in the DOE report focuses on. red regions indicate that the models are warming faster than observations, blue indicates the opposite.

I believe the author of Figure 5.9 of the DOE report is Dr. Roy Spencer. I should note that I have criticized Spencer for this type of cherry picking (Dessler, 2011):

First, [Spencer and Braswell] analyzed 14 models, but they plotted only six models and the particular observational data set that provided maximum support for their hypothesis. Plotting all of the models and all of the data provide a much different conclusion.

This region is special

But this leads to the question of why models do so poorly in this one particular region. It turns out that this is a special region because of intensive agriculture there (e.g., Mueller et al., 2016; Alter et al., 2018). This is the most agriculturally productive region on the planet, and land-use changes over the last few decades have largely offset greenhouse gas warming here.

To the extent that models have problems in this very small region, it's connected to how well the models are handling the specific land-use changes occurring only in this region, not how well they represent global warming.

Conclusions

Climate models do an excellent job of simulating the global climate. This section focuses on one region (making up less than 1% of the area of the planet) where the models don't do as well as in other regions. The analysis ignores the impact of unforced variability, which makes the models look worse than they actually are. We also understand that this is a unique region of the planet and how models do here tells us little about how well the models do globally.

To fix this, the authors must:

- Acknowledge that they selected the region where the models do worst
- Acknowledge that global analyses shows that the models do quite well at simulating the magnitude of historical warming
- Improve this analysis using a multi-ensemble approach that demonstrates that the models do better than the plot that's presently in the report
- Explain why models do poorly here (due to intensive agriculture in this region); explain how this does not apply anywhere else on the globe

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Code to reproduce the plots: https://github.com/aedessler/TCB_Trump_Graphic

Comment on the DOE CWG report, Section 6.2: Hurricanes and Tropical Cyclones

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Pages: 46, Section 6.2, Hurricanes and Tropical Cyclones (Executive Summary)

Comment type: Technical

Comment:

The Executive Summary states:

“Extreme convective storms, hurricanes, tornadoes, floods and droughts exhibit considerable natural variability, but long-term increases are not detected.”

In regards to hurricanes, this statement is true only for overall frequency. The key research findings on observed changes in hurricane hazards have been omitted, which is that hurricanes are becoming more hazardous, reaching higher intensity, intensifying more quickly, and producing more rainfall, which is increasing their inland impacts.

Pages: 48-52, Section 6.2, Hurricanes and Tropical Cyclones

Comment type: Technical

Comment:

This section of the DOE CWG Report begins by arguing that existing historical records of hurricanes and tropical cyclones (hereafter collectively called TCs) are generally too short or too flawed to detect plausible trends of such events. However, findings in the report rely almost entirely on analysis of such historical trends to reach conclusions that are only partially and selectively in agreement with those of the far more comprehensive discussions in IPCC AR6 and the broader scientific literature. Where the observational record of TCs fits a framework that suggests no change in the severity of TC impacts in recent years, the authors argue that the observational record proves that a warming climate is not causing TC hazards to worsen; no robust statistical analyses are offered

to support these statements. However, in cases where the broader scientific community has been able to perform robust statistical analyses of the observational record that suggest that TC impacts have worsened as the climate has warmed, the DOE CWG authors declare that the observational record is too short to assess any meaningful trends.

In general, Section 6.2 of the DOE CWG Report relies upon selectively chosen references, and contains a number of critical omissions that result in an incomplete presentation of the scientific community's knowledge regarding the ways in which TCs and their impacts are changed by a warming climate.

Critical omissions from Section 6.2 of the DOE CWG Report are listed below. These points will be elaborated and references are provided in the subsequent text:

- The DOE CWG Report neglects important evidence from theory and models reported in AR6 and in subsequent peer-reviewed literature.
- The DOE CWG Report stresses the finding that there are no statistically significant trends in, e.g., U.S. landfalling hurricane frequency, while not informing the reader that a) this outcome is in fact what is expected based on the current science and b) that plausible trends cannot easily be detected from a short historical record given the random noise and natural variability in the series.
- At the same time, Section 6.2 of the DOE CWG Report ignores more recent peer-reviewed literature as well as its own non-peer-reviewed data regarding hurricane intensity: there is an upward trend in the proportion of major tropical cyclones, a trend that was predicted.
- The DOE CWG Report does not directly address the IPCC AR6 findings that 1) tropical cyclone rainfall is already increasing and expected to continue to increase rapidly in the future (based on simple physics); and 2) TC intensification rates are already increasing and expected to continue to increase in the future (based on well-established dynamical theories). These are serious omissions, as flooding is the main source of mortality and damage in TCs, and increasing intensification rates will shorten the time window for preparations and evacuation.
- Although storm surge flooding has historically been one of the most damaging and deadly aspects of TCs, the authors do not address the scientific consensus that has shown that rising sea levels will amplify future storm surge flooding, and a recent study showing that extreme surges are already likely increasing along parts of the U.S. coastline.

Page: 48

Comment type: Technical

Comment:

The Report quotes from AR6:

AR6: “There is *low confidence* in most reported long-term (multidecadal to centennial) trends in TC frequency or intensity-based metrics due to changes in the technology used to collect the best-track data.” (IPCC, 2021 p. 1585)

However, the next sentence in the IPCC AR6 report makes an important clarification:

“This should not be interpreted as implying that no physical (real) trends exist, but rather as indicating that either the quality or the temporal length of the data is not adequate to provide robust trend detection statements, particularly in the presence of multi-decadal variability.”

This is a recurring issue in Section 6.2: the absence of statistically significant trends in the historical records does not mean that changes are not occurring. As will be outlined below, there are other good reasons to believe that changes in TC intensity and impacts are already occurring. Furthermore, there is no consensus prediction as to whether the number of TCs will increase or decrease (e.g., Knutson et al. 2020; Seneviratne et al. 2021); therefore, absence of a trend does not contradict the science.

Pages: 48

Comment type: Reference

Comment:

The following quote is attributed to IPCC, 2023 SPM, p. 9:

“It is likely that the global proportion of major (Category 3-5) tropical cyclone occurrence has increased over the last four decades ... There is low confidence in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones.”

The quoted text does not appear in the document identified as IPCC, 2023, SPM (full citation below as IPCC 2023). More likely, this is an edited and incorrectly cited quote from the 2021 IPCC AR6 Working Group 1 Summary for Policy Makers (cited below as IPCC 2021), which in full, reads:

“It is likely that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades, and it is very likely that the latitude where tropical cyclones in the western North Pacific reach their peak intensity has shifted northward; these changes cannot be explained by internal variability alone (medium confidence). There is low confidence in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones. Event attribution studies and physical understanding indicate that human-induced climate change increases heavy precipitation associated with tropical cyclones (high confidence), but data limitations inhibit clear detection of past trends on the global scale.”

Page: 48 / Figure 6.2.1 (on page 49)

Comment type: Technical

From the Report:

“Figure 6.2.1 shows that on average, each year there are about 50 hurricanes, with about 25 reaching major hurricane status (Maue, 2025). There is substantial year-to-year and decadal variability, a weak decrease in the number of hurricanes, and a slight but insignificant increase in the number of major hurricanes. These two trends combine to create an overall increase in the proportion of major hurricanes.

Comment:

It is worth noting that this change in the proportion of major hurricanes, which is supported in AR6 and other published studies from the peer-reviewed literature (e.g., Seneviratne, et al., 2021; Kossin et al., 2020), is statistically significant (based on records from the standard historical database of TCs), even though the trends in number of hurricanes and major hurricanes are not statistically significant.

Page: 50

Comment type: Technical

From the Report:

“However, following 2005 there were no major hurricanes striking the U.S through 2016, the longest such period since 1920.”

Comment:

This statement about the major hurricane drought is correct. However, there have also been 10 major U.S. hurricane landfalls in the 8 years after the drought (Harvey, Irma, Michael, Laura, Zeta, Ida, Ian, Idalia, Helene, and Milton), not including Maria in Puerto Rico, which would make it 11. These contrasts illustrate the weakness of using short records of infrequent events to identify important trends.

Page: 51

Comment type: Technical

From the report:

“...it is remarkable that the highest year in the entire record is 1886, with 7 hurricane landfalls, when human influences on the climate were much smaller than they are today.”

Comment:

As noted above, there is no consensus prediction for trends in numbers of hurricanes, and especially not for landfalling hurricanes. Therefore the largest number occurring in 1886 is not in contradiction with AR6 or the published literature.

Page: 51

Comment type: Technical

From the Report:

“In summary, analyses of both global and regional variability and trends of hurricane activity provide the basis for detecting changes and understanding their causes.”

Comment:

This statement is incomplete. Theory (Emanuel 1987; Ramsay and Sobel 2011; Emanuel 2017b) and modeling (Walsh et al. 2019; Knutson et al. 2020; Roberts et al. 2020, to name just a few of many papers) both provide reasons to believe that, in a warming climate, the fraction of major TCs will increase, and that TCs will get stronger, produce more rain, and intensify more rapidly. These findings support a statement from the IPCC AR6, cited by the authors of the DOE CWG: “...it is *likely* that the global proportion of major hurricanes (Categories 3-5) has increased in the last four decades.” As noted by IPCC AR6, such changes cannot be explained by natural variability alone.

Page: 51

Comment type: Technical

From the Report:

“The relatively short historical record of hurricane activity, and the even shorter record from the satellite era, is not sufficient to assess whether recent hurricane activity is unusual relative to the background natural variability.”

Comment:

Similar to what is noted in the comment above for p. 48, Section 6.2 of the DOE CWG Report, the statement above should have added that the observational dataset cannot rule out plausible underlying trends in U.S. landfalling hurricanes, and that there is no consensus prediction that TC frequencies will change.

Page: 51 / Table 6.2.1

Comment type: Technical

From the Report:

Table 6.2.1 lists the estimated wind speed intensities of the 10 strongest hurricanes to make landfall in the U.S.

Comment:

By definition, landfalling hurricanes are extremely rare events, which means that an even longer historical record would be required to assess any plausible trend. Therefore, any trend, positive or negative, that might be inferred by some subjective standard (e.g., when the three most intense U.S. landfalling TCs occurred) cannot be considered statistically significant. Therefore, no conclusions, either positive or negative, can be drawn from this table.

Page: 51

Comment type: Technical

From the Report:

“While it has long been hypothesized that a rising global sea surface temperature would cause an increase in hurricane intensity, identification of any significant trend in the hurricane data is hampered by a short data record and substantial natural variability.”

Comment:

There are important trends in the data that *have* been identified in the peer-reviewed scientific literature. First, using a homogenized satellite record, Kossin et al. (2020) showed statistically significant positive trends in the proportion of tropical cyclones that achieve major intensity. Second, the latitude where the lifetime maximum intensity (LMI) occurs has been increasing (Kossin et al. 2014; Studholme et al. 2022), although most of the signal is due to changes in the West Pacific (Kossin et al. 2016; Zhan and Wang 2017). Third, Bhatia et al. (2019, 2022) documented an increase in the frequency of “rapid intensification” events, which is when a TC increases in wind speed intensity by 30 knots or more in 24 hours. Klotzbach et al. (2022) and Garner (2023) also find an increase in the frequency of extreme intensification events within the observational record. These results are supported by modeling studies showing that intensification rates increase rapidly with temperature (Ramsay et al 2020). These findings are critical to TC impacts in U.S. coastal communities, given that such events are associated with larger forecast errors and larger negative impacts at landfall (Emanuel and Zhang 2016; Emanuel 2017b). Finally, Guzman and Jiang (2021) and Tu et al. (2021), both using global satellite observations of rainfall, found statistically significant positive trends in rainfall associated with TCs.

Page: 51

Comment type: Technical

From the Report:

“Process-based understanding also suggests that storm surges and rainfall from hurricanes should be increasing with warmer temperatures. However, the relatively small number of hurricanes with varying landfall locations and the complex dynamics associated with each storm preclude meaningful detection of change.”

Comment:

In regards to rainfall, recent studies have identified observed increases in inland hurricane rainfall over land (Uehling and Schreck 2024, Maxwell et al 2021) and as noted above, the scientific community has also identified trends in TC rainfall rates over

the ocean (Guzman and Jiang 2021; Tu et al. 2021). This observed outcome is consistent with simple physics (more water vapor in saturated air at warmer temperatures, the Clausius-Clapeyron relation) and has been confirmed by many weather and climate models (Reed et al 2022; Stansfield and Reed 2021; Stansfield and Reed 2023; Stansfield and Rasmussen 2025). Moreover, rainfall-induced inland flooding impacts are rapidly increasing, as the top cause of hurricane fatalities has shifted sharply from storm surge to inland flooding since 2013 (Brennan et al. 2023). As a result, hurricanes increasingly pose a major inland flood risk regardless of their intensity at landfall. Empirical models show that economic damage increases with rainfall amounts and these damages are expected to continue to increase with warming (Gori et al. 2025).

For storm surge, recent research has shown in the observational record a likely increase in extreme surge levels in multiple regions along the U.S. coastline (Morim et al. 2025) as well as in Japan (Islam et al 2021). Additionally, numerous studies have shown how rising sea levels will directly translate to higher storm surges and also greater compound flooding from surge and rainfall (Garner et al., 2017; Muis et al. 2020, Gori and Lin, 2022; Mayo and Lin, 2022).

To ensure that Section 6.2 of the DOE CWG reflects an accurate knowledge of the impacts of climate change upon TCs, the following changes are recommended:

- Any framework that selectively identifies trends (or lack thereof) within the observational record of TCs, while overlooking other statistically robust trends in the record, should be abandoned.
- A more thorough review of the literature should be completed, and findings from modeling and theoretical studies assessing the impacts of climate change upon TCs should be incorporated into the document.
- The text should be revised to show that the proportion of TCs that reach major hurricane status has already increased, and is expected to continue to do so as the planet warms.
- The text should address the evidence for increasing TC intensification rates
- The chapter should discuss the scientific evidence showing that rainfall and associated inland impacts of TCs have already begun to worsen, and will continue to become more extreme with additional warming.
- The report should acknowledge observed and projected changes in sea level, and the fact that such changes in sea level will serve to amplify the severity of TC storm surge events.

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Comment on Section 6.3: Extreme weather: Temperature extremes

John M. Wallace, Chan-Pang Ng, and David Battisti

Section 6.3. Temperature extremes (p. 52-60)

The impacts of human-induced climate change are felt every day and at every location, but they are front-page news only when temperatures reach record-breaking levels. Seemingly paradoxically, the more extreme the high temperature event, the smaller the fractional contribution of climate change relative to that attributable to natural variability. The DOE CWG report's focus on extreme events, rather than considering the shift in the whole frequency distribution of temperature, is contrived to minimize the apparent influence of climate change. But the authors go a step farther: they misinterpret and distort the observations on extreme events to support their narrative.

Section 6.3.1 "Temperatures in the U.S. are becoming less extreme" (p. 53-56)

The argument that supports this outrageous claim is that over parts of the continental United States, the all-time high temperature records were set during the late 1920s and 1930s. Apart from a quote from NC4, which makes the same (factually correct) point, the report contains no mention of the Dust Bowl in the southern Great Plains, arguably the greatest environmental disaster in American history, brought on by agricultural practices designed to maximize short term profits without regard for the long-term consequences, e.g., see Egan and Lawlor (2006). The authors use the extremely hot, dry meteorological conditions observed during this slowly evolving tragedy as a benchmark for assessing whether human-induced global warming is detectable in statistics of extreme events, and they reject observational evidence based on analyses that exclude their benchmark era. In effect, they are treating the extreme weather conditions of the Dust Bowl era as if they were natural variability that should be expected to occur from time to time, even in the absence of human influences. In doing so, they are formulating their statistical analysis in terms of an inappropriate null hypothesis that cannot be falsified. This is rhetoric, not science.

Contrary to the authors' claims, the human-induced global warming signal is clearly discernible in all-time high and low temperature records over the continental United States and throughout the world, as shown in Fig. 1. Similar evidence was presented in Meehl et al. (2009) and the Summary for Policymakers of the WG1 Report of IPCC in 2021, but it is ignored in the DOE Report.

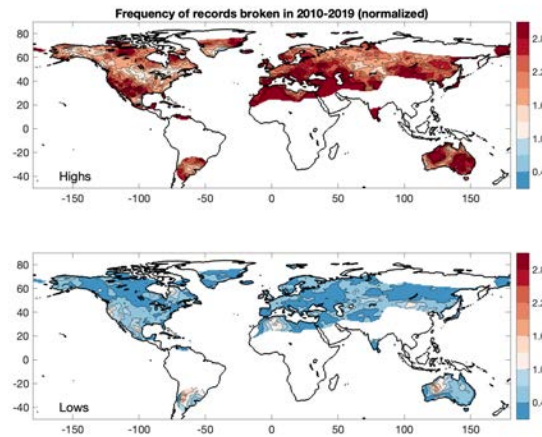


Figure 1. Numbers of all-time high and low temperature records that were set during the decade 2010-2019 divided by the expected values based on chance. Record high temperatures are being broken at a rate 2-3 times greater than expected by chance; record low temperatures are being broken at less than half of what would be expected by chance. Based on Berkeley Earth, 1920-2019.

When viewed from a global perspective, it becomes apparent that the spate of all-time high temperature records that were set during the late 1920s and 30s is a regional feature associated with the Dust Bowl. The high temperature records at the overwhelming majority of the grid points occurred recently, as shown in Fig. 2.

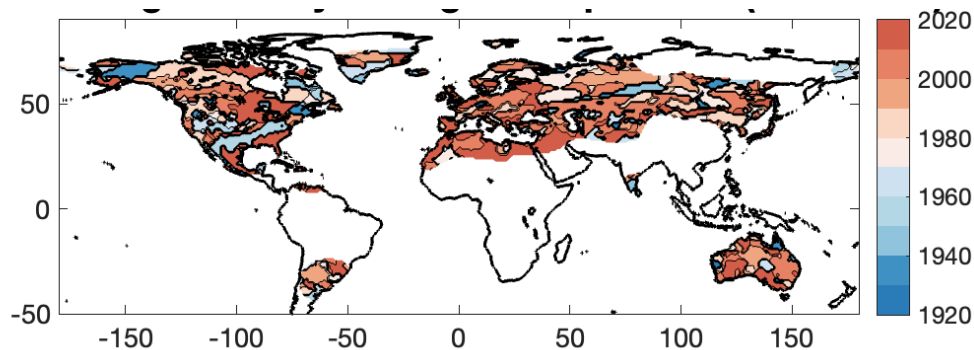


Figure 2. The decade in which the all-time high temperature record was set. Based on Berkeley Earth, 1920-2019.

6.3.2 Exceedances of a heat threshold (p. 56-57)

Based on the same bogus Dust Bowl benchmark criterion, the authors argue that the frequency of days with high temperatures above 95°F isn't changing. Unless the positive tail frequency distribution of temperature is contracting—and that's highly unlikely—the shifting of the frequency distribution of temperature toward higher values has to be accompanied by an increase in the frequency of days with temperatures above specified thresholds like 95°F. I can only conclude that here must be something wrong with analysis that was used to produce *Figure*.

6.3.5 with the data that went into it. Our analysis, shown in Fig. 3, is indicative of a robust rising trend the parallels the rising mean temperature.¹

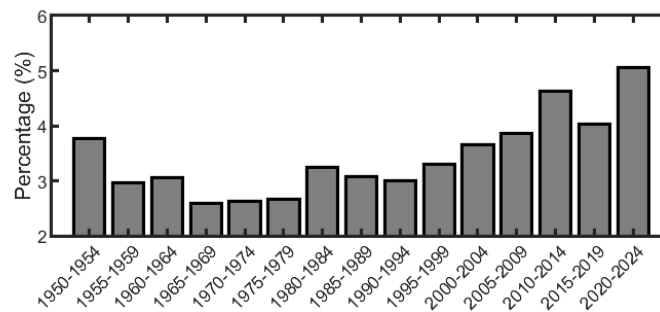


Figure 3 Fraction of 2.5° x 2.5° lat / lon gridpoint-days in the ERA5 reanalysis in which the daily maximum temperature exceeded 95°F.

6.3.3 Heatwaves (p. 57-60)

The same bogus Dust Bowl benchmark criterion is invoked again in this subsection to argue that the frequency of heat waves is not increasing. There's no denying that heat waves during the Dust Bowl era were beyond the pale of anything we've seen since that time, but that doesn't prove that human-induced global warming doesn't increase the frequency of occurrence of heat waves. Just as a rising tide lifts all boats, human-induced global warming lifts each day's temperature. If the local temperature has risen by, say, 3°F in response to global warming over the past 50 years, then a day on which the temperature would have reached 95°F fifty years ago would reach 98°F today, and the same is true for any other prescribed threshold. To deny that rising mean temperatures affect the statistics of heat waves is equivalent to denying the reality of human-induced global warming.

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¹ The four-year interval 1952-55 was indeed anomalously hot, especially in the central US, but not as hot as it was during the Dust Bowl. era.

Section 6.3: Extreme temperatures

Andrew E. Dessler¹, Karen McKinnon², Enrique Sánchez³, Lucas R. Vargas Zeppetello⁴

Section 6.3: pages 52-60, Figures 6.3.3, 6.3.5, and 6.3.6

Comment Type: Technical

Comment: The Chapter 6 summary of the DOE CWG report states: “Most types of extreme weather exhibit no statistically significant long-term trends over the available historical record. While there has been an increase in hot days in the U.S. since the 1950s, a point emphasized by AR6, numbers are still low relative to the 1920s and 1930s.” The executive summary (p. ix) states that “Most extreme weather events in the U.S. do not show long-term trends.”

These are misleading claims that ignore the well-established connection between anthropogenic global warming and extreme temperatures. The intellectual framework employed by the DOE CWG ignores a wealth of peer-reviewed science linking anthropogenic global warming to changes in extremely high temperatures while focusing on trends, which conflates a decadal climate anomaly over the Eastern U.S. during the 1930s with the long-term global trend over the entire record. We address this issue in our “Intellectual Framework” section.

In addition, the DOE CWG report’s use of non-homogenized station data is also inappropriate for understanding continental averaged trends in extreme temperatures. We address this issue in our “Data and Analysis” section and provide a complementary analysis that shows larger trends in extreme temperatures. **Based on the preponderance of peer-reviewed literature and our own analysis of gridded daily temperature data, there is little doubt that anthropogenic climate change driven by greenhouse gas emissions is making extreme heat more frequent and severe, both in the United States and across the globe.**

To correct these issues, the following changes must be made in the DOE CWG document:

1. Replace the problematic framework used here (“there is no trend in extreme heat in the U.S.” implying that climate change is not making extreme heat more severe) with one that reflects the multiple processes that have contributed to climate variability in the U.S.
2. Accurately summarize the peer-reviewed literature that has demonstrated the fundamental physical link between long-term global warming and changes in extreme temperatures.

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3. Validate analysis using homogenized and bias-corrected data sets.
4. Acknowledge that a focus on the U.S. is not representative of the planet as a whole.

(1) Intellectual Framework

(a) Conflation of Timescales

The DOE CWG report repeatedly refers to the 1930s as a period of extremely high temperatures throughout the continental United States. From this, they make the statistically dubious leap that, because the 1930's extreme temperatures are comparable to today's temperatures (Fig. 1), then climate change cannot be contributing to more extreme heat today.

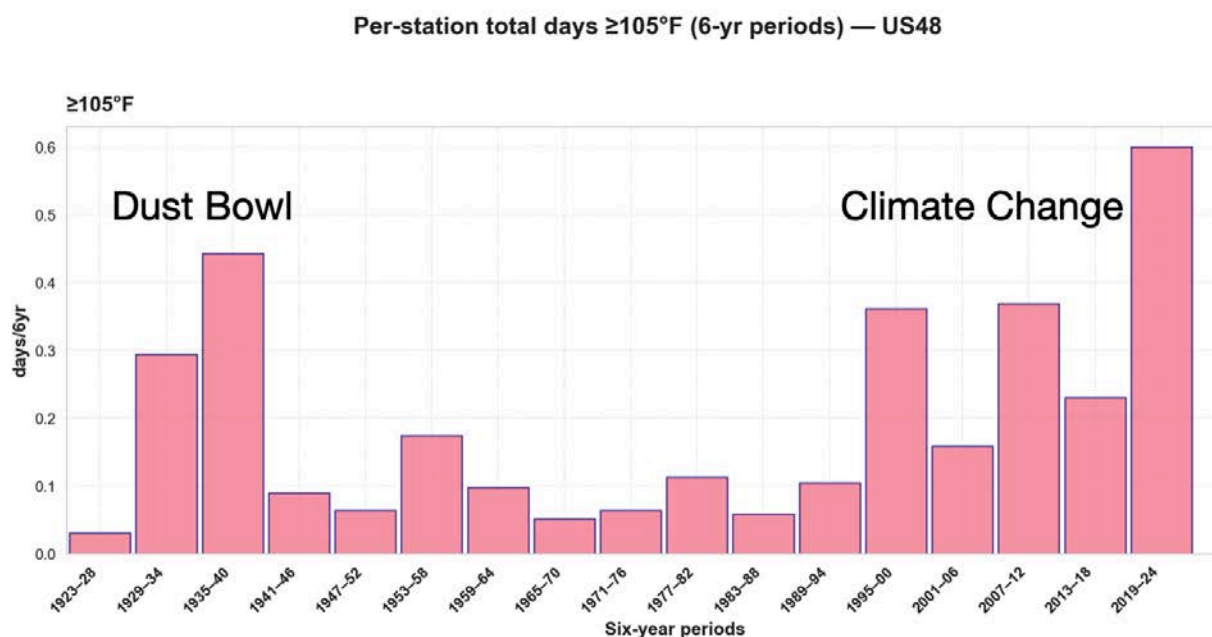


Figure 1: Number of days in 6-year periods (per grid point) that exceed 105°F . Details of this plot are provided in Section 2 of this comment.

However, this conclusion falls apart when crucial physical context is added. The critical missing piece in this analysis is recognizing that the extreme heat of the 1930s was driven by the unique and devastating conditions of the Dust Bowl era (Schubert et al. 2004, Cook et al. 2009). Massive agricultural mismanagement, unforced climate variability, and severe drought, caused the destruction of prairie ecosystems and created an environmental catastrophe that amplified heat extremes through altered land-surface interactions and reduced evapotranspiration (Donat et al. 2016a, pp. 190-191).

These specific conditions — widespread soil erosion, denuded landscapes, and the particular SST patterns of that decade — do not exist today. Today, the increases in extreme heat events are

occurring due to fundamentally different physics and can be confidently attributed to the enhanced greenhouse effect from human emissions (Seneviratne et al., 2021).

This case perfectly illustrates why relying on naive statistical analysis without considering underlying physical mechanisms leads to profound errors. A proper scientific assessment must account for the different drivers of extreme events across different time periods. In adding this context, the chart actually provides compelling evidence for climate change impacts rather than refuting them.

The claim that “For CONUS as a whole, the evidence in this section suggests GHG emissions have had little-to-no effect on heatwaves” is therefore misleading because it combines climate change with other physical drivers of climate variability, therefore ignoring key physical context.

A more correct interpretation of the results from the DOE CWG working group is that multiple processes have influenced temperature extremes in the continental U.S. over the last century, with anthropogenic climate change playing a dominant role in recent decades.

(b) Peer-Reviewed Literature

Analyses of extreme temperatures suggest that changes in extreme summertime temperatures follow changes in the median (McKinnon et al. 2016, 2024). **As noted by authors of the DOE CWG report, there has been an increase in the frequency, intensity, and duration of heat waves globally since the 1950s. In virtually all of the peer-reviewed literature, long-term anthropogenic climate change driven by greenhouse gas emissions has been invoked to explain this increase** (Perkins-Kirkpatrick & Lewis, 2020, Seneviratne et al. 2021). One exception to this pattern is the U.S. Midwest where extremely high temperatures have decreased in intensity over the recent observational record; however this has been shown to be a response to agricultural intensification that is independent from the influence of anthropogenic global climate change (Mueller et al. 2016, 2017).

(2) Data and Analysis

The DOE CWG report’s analysis of temperature extremes relies exclusively on daily data from the U.S. Historical Climate Network (USHCN). Multiple studies have shown that time of observation bias, widespread station moves, equipment changes such as the transition from liquid-in-glass thermometers to MMTS sensors, and changes in site surroundings have introduced both abrupt and gradual shifts in measured temperatures unrelated to long-term anthropogenic climate change (Menne et al. 2009, Lawrimore et al. 2011). The DOE CWG report claims that “Although there are certainly errors in the dataset, including unresolved spurious warming due to [urban heat island] effects that especially bias T_{min} records, this data

set is sufficiently accurate for assessing trends in Tmax heat extremes.” (p. 53). There is no citation for this claim. However, the sentence only acknowledges problems associated with the urban heat island phenomenon, ignoring problems from the many other biases in the data set, such as changes in equipment, changes in time of observation, changes in station location. While station datasets such as USHCN and GHCN are used for climate studies given their uniquely long records, care must be taken to assess and quantify the potential influences of inhomogeneities, and results should be compared across multiple datasets when possible.

(a) Trends in Extreme Events Using Daily, Homogenized Data

The DOE CWG report concluded that there were more hot record-setting days in the 1930s than any other decade in the observational record (reproduced as Fig. 2a below), and this forms key evidence for their claim that “Most extreme weather events in the U.S. do not show long-term trends.” However, the dataset they used in the DOE report (USHCN) includes many biases that have not been removed, as the DOE CWG report acknowledges.

We have conducted an identical analysis to the one performed in the DOE CWG report using daily gridded data from Berkeley Earth (Fig. 2b). The Berkeley Earth dataset developed by Rhode et al. (2013) has been extensively used in the peer-reviewed literature (e.g., Perkins-Kirkpatrick & Lewis, 2020, Patel et al. 2024). Importantly, the Berkeley dataset adjusts for the well-known biases in the USHCN data.

The Berkeley figure (Fig. 2b) shares some key features with the DOE CWG report’s analysis (Fig. 2a), particularly the high number of temperature records in the 1930s.

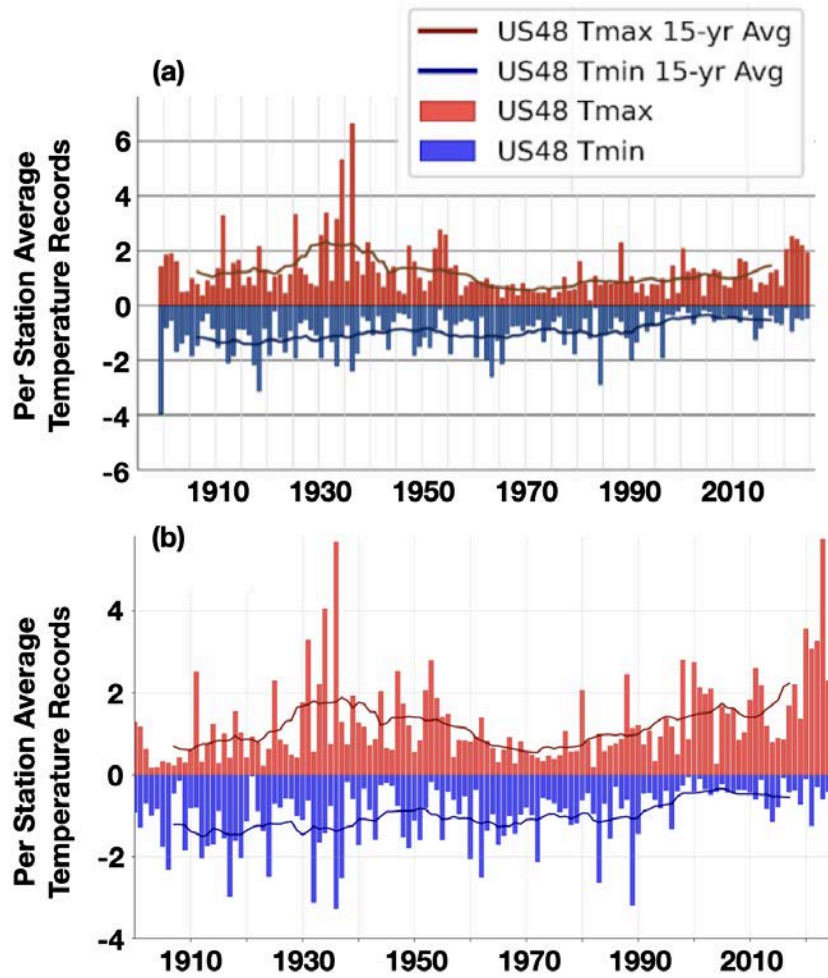


Figure 2. Number of daily record high (red) and low (blue) temperatures for warm and cold seasons in the Continental United States (US48). Solid lines represent the 15-year running, centered average. Panel (a) is adapted from Figure 6.3.3 of the DOE CWG report and is based exclusively on USHCN stations. Panel (b) is the same analysis conducted on the homogenized and gridded Berkeley Earth data. In this plot, the grid points are considered “stations”.

However, one key difference stands out: **in our calculation, the most recent few years have had as many record-breaking high temperatures as the 1930s. In fact, the year with the most record-breaking hot days is 2023.** This is also true in the 15-year running average, where our analysis shows that the most recent 15-year period is the first where more than two temperature records were set per station per year.

We conclude that an important conclusion of the DOE CWG report, “While there has been an increase in hot days in the U.S. since the 1950s, a point emphasized by AR6, numbers are still low relative to the 1920s and 1930s” (p. 46) is very likely not correct.

The consequences of the DOE CWG report’s reliance on non-homogenized station data also influence the analysis presented in Fig. 6.3.5 and 6.3.6, that are claimed to illustrate that the 1930’s was the decade with the most exceedances of 95°F and the most heat wave days. In our analysis of the Berkeley Earth data, we find that the exceptional warmth of the 1930s is not as extreme as in the most recent decade (Figs. 3 and 4).

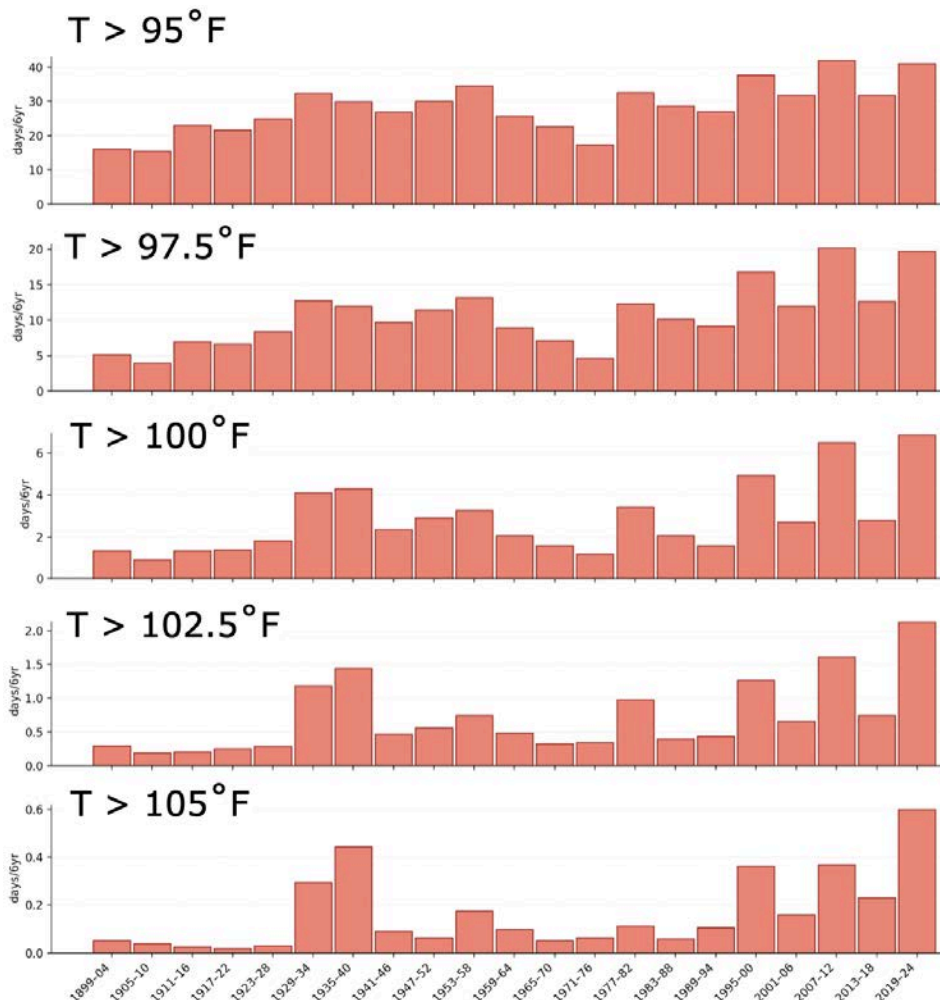


Figure 3: Number of days per grid point per six-year period where temperature exceeded a particular threshold from Berkeley Earth daily data averaged over the Continental U.S.

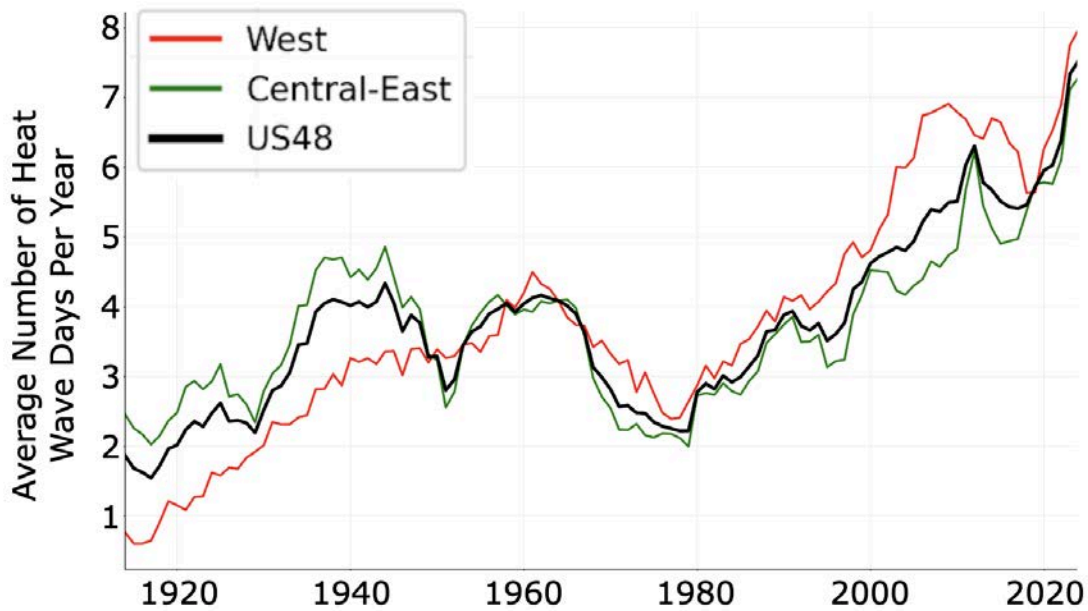


Figure 4: Per-grid-point average number of heat wave days per year from daily Berkeley Earth observations. The black line shows the average across the Continental U.S., the red line shows the average west of the Rocky Mountains, and the Green line shows the average east of the Rocky Mountains.

In general, our analysis of the Berkeley Earth data demonstrates that extreme high temperatures have become more frequent over the Continental U.S. over the past two decades than at any point in the previous observational record. **Thus, the conclusion of the DOE CWG report that “Most extreme weather events in the U.S. do not show long-term trends” aside from being misleading and ignoring the physical processes responsible for natural climate variability (see Section 1), is not a robust conclusion because it depends on the data set and the metric under consideration.**

(b) An Absent Global Perspective

The focus of Section 6.3 of the DOE CWG report is on temperatures in the Continental U.S. This is a clear example of **cherry picking**, defined to be an intentional selection of a small subset of the data that gives a different conclusion to the entire data set. To illustrate this, we show global summertime average high-temperatures from the Berkeley Earth dataset from 1930-1939 and from 2014-2024 (Figs. 5a and b, respectively).

Globally, summertime high temperatures are consistently higher in the last decade than they were in the 1930s (Fig. 5c). The only exception is the Eastern United States, where temperatures were warmer during the 1930s due to known decadal climate fluctuations discussed earlier (Schubert et al. 2004, Cook et al. 2009, Donat 2016a, 2016b) and where temperatures have been cooler

than normal over the past few decades due to agricultural intensification (Mueller et al. 2016, 2017).

The decadal climate anomaly that drove an increase in extremely high temperature during the 1930s was tightly confined to the Eastern United States and does not represent a global pattern of how long-term anthropogenic climate change drives increases in extremely high temperatures.

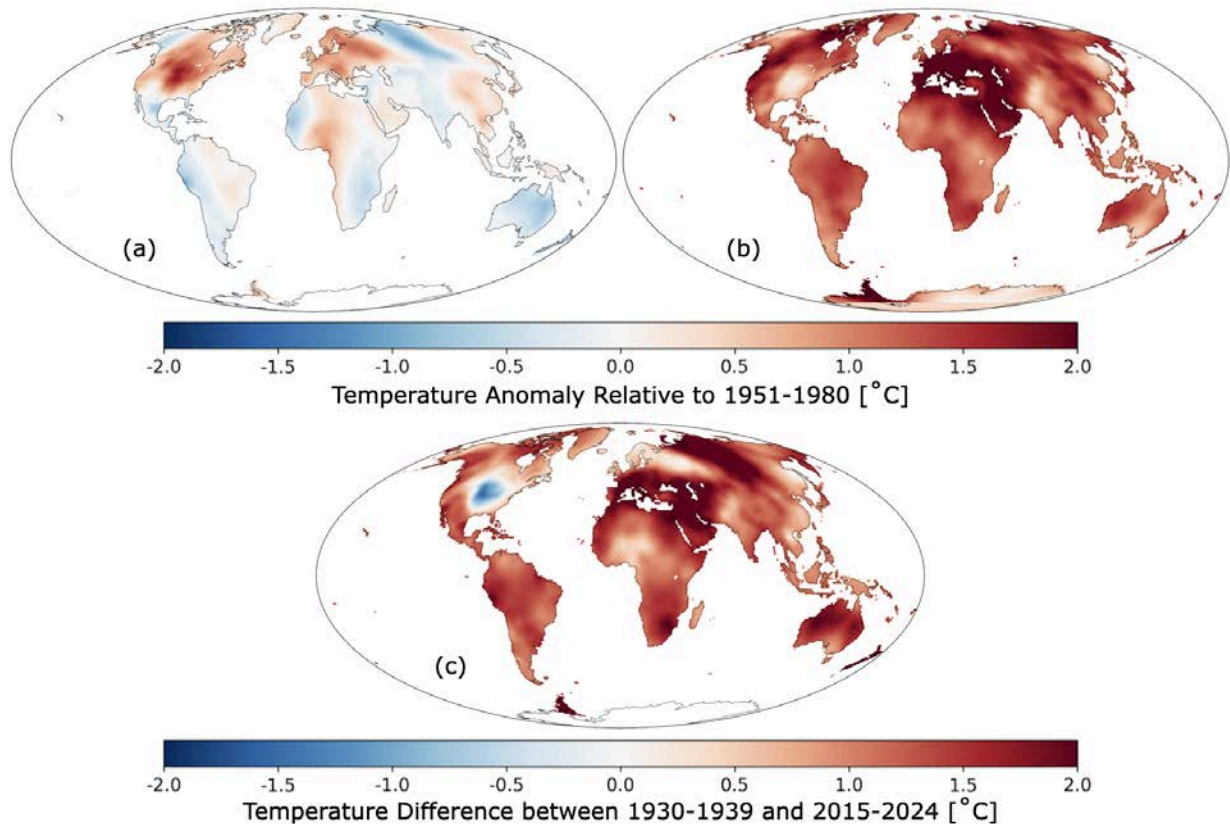


Figure 5: Panels (a-b) show summertime (June, July, August) average high temperature anomalies relative to the 1951-1980 reference climatology for 1930-1939 and 2015-2024 periods, respectively. Panel c shows the difference between panels a and b.

To demonstrate the regional nature of the 1930s heat anomaly in the Eastern U.S., we have reproduced Figs. 6.3.3, 6.3.5, and 6.3.6 (Figs. 6-8), but included the entire land surface of the northern hemisphere midlatitudes (rather than only considering the Continental United States as is done in the DOE CWG report). Investigating at a larger scale than the U.S. dilutes the impact of the Dust Bowl in the 1930s, and makes the impact of climate change much more apparent.

Our results align with the peer-reviewed literature on heat waves (see above) and demonstrate that severe heat is getting worse throughout the northern hemisphere midlatitudes. We note again that warm temperatures in the 1930s due to a particular set of circumstances is fully compatible with the fact that climate change is making today's extreme heat more intense (see Fig. 1).

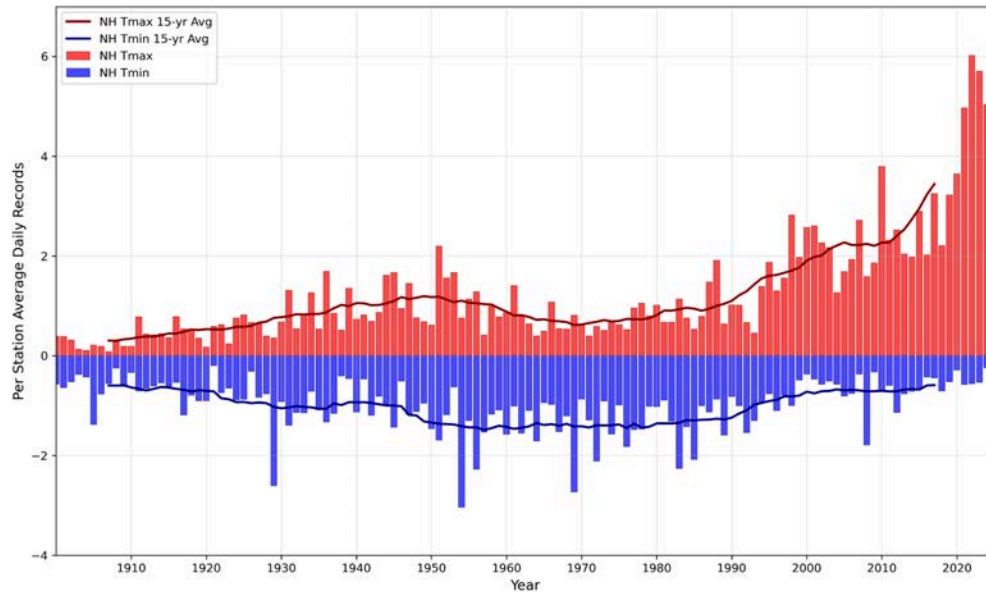


Figure 6: Record-setting land temperatures for the entire northern hemisphere mid-latitudes (24°N-50°N) calculated with the same approach as Fig. 2 using the Berkeley Earth Data.

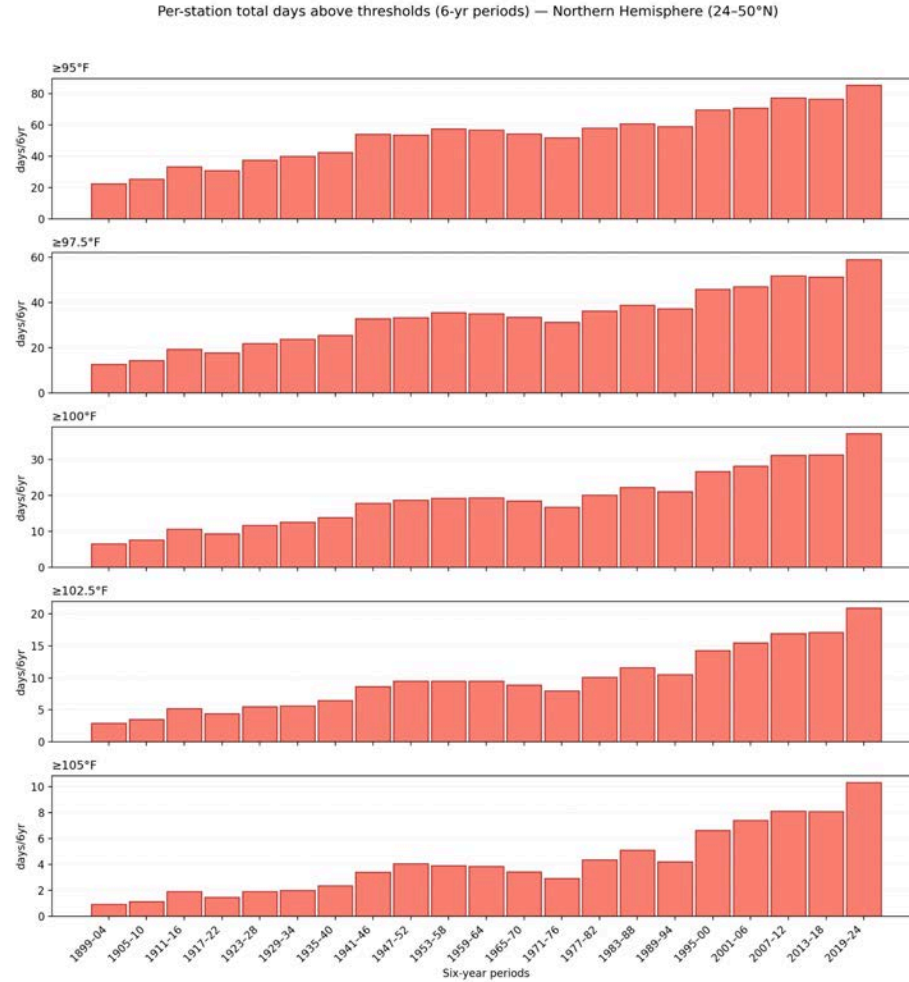


Figure 7: Exceedances of particular temperature thresholds averaged across stations in the Northern Hemisphere land midlatitudes (24°N–50°N). Analysis was identical to that performed in Fig. 3, except that we used all Berkeley Earth grid cells in the Northern Hemisphere midlatitudes.

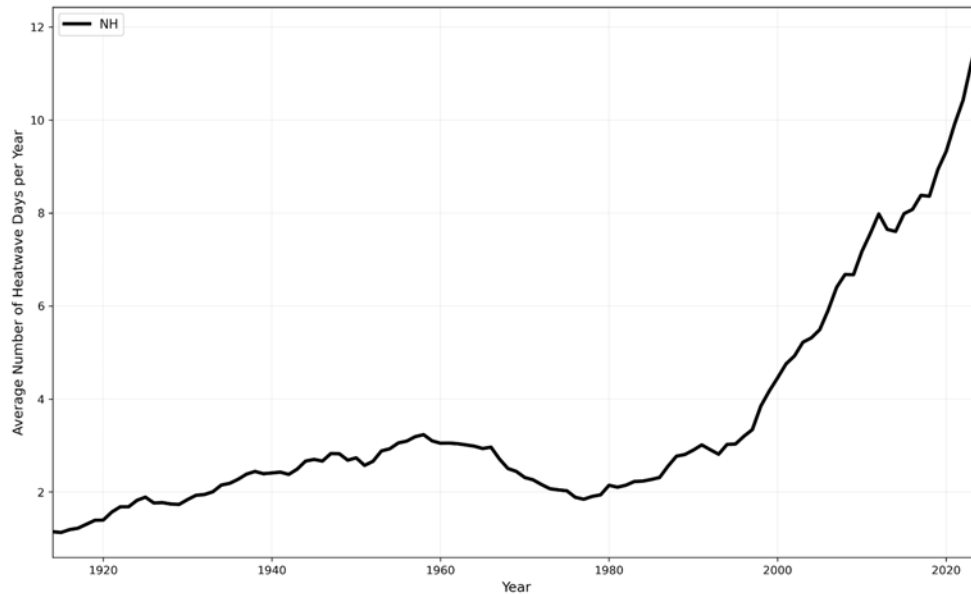


Figure 9: 15-year running average of number of heat wave days per station per year averaged across all Berkeley Earth grid cells in the Northern Hemisphere land midlatitudes (24°N-50°N). Analysis is identical to that presented in Fig. 4, except for the number of grid cells included in the Analysis.

Reproducibility

Many of the details of the analysis conducted by the DOE CWG report authors are not provided in section 6.3. The DOE CWG report uses an enhanced USHCN dataset created by merging data from nearby stations when original stations had gaps or closures and regriding to a 0.5° grid over the Continental U.S. However, there is no documentation on the details of this important bias correction procedure. In addition, they did not archive the code that was used to produce the figures critiqued in this section. **This lack of documentation of the data and methods used in the DOE CWG report means that the work is fundamentally unreproducible. As a result, the analysis likely does not adhere to the “gold standard science” Executive Order or the Information Quality Act.**

Conclusions

The report's central claim that “Most types of extreme weather exhibit no statistically significant long-term trends over the available historical record” is **fundamentally misleading** when our physical understanding of the 1930s is considered, and **appears to be inaccurate** for some metrics or data sets, based on our analysis of homogenized observations.

The peer-reviewed science is clear: **long-term anthropogenic climate change is making extreme heat more extreme in both the Continental United States and globally.**

Physical Understanding: The DOE CWG report's result that no significant trends in U.S. extreme temperatures exist across the instrumental record rests entirely on the decadal 1930s heat anomaly in the Eastern U.S. However, this anomaly is well-understood as resulting from specific regional factors including drought, land mismanagement, and natural variability during the Dust Bowl. The fact that the 1930s were warm in the Eastern U.S. does not contradict the scientific consensus that long-term anthropogenic climate change is exacerbating extremely high temperatures today.

The implication of the DOE CWG report that “the 1930s were warmer than today, so climate change is increasing extreme temperatures” is supported only by ignoring the physical understanding of different timescales of climate variability. **Any future version of this report must incorporate fundamental knowledge of multiple timescales related to climate variability. They should also acknowledge that simple physical arguments assure us that climate change is indeed making extreme temperatures more extreme.**

Data Quality Issues: The DOE CWG report relies on daily USHCN station data that contain well-documented non-climatic biases unsuitable for climate analysis, including time of observation bias, station relocations, equipment changes, and urban heat island effects. While the authors of the DOE CWG report did re-grid the data to ameliorate sampling errors, they provided no documentation of this procedure and did not execute a homogenization procedure to remove other biases. In personal communications between one of us (AED) and the authors of the DOE CWG report, the DOE authors claimed that the biases are actually small but provided no evidence to support that other than anecdote, motivated reasoning, and arm waving. **They must improve this analysis with better data and quantitative and comprehensive characterization of the errors.**

Corrected Analysis: Using the spatially uniform, homogenized Berkeley Earth dataset reveals that recent years have experienced more extreme heat days than the 1930s peak. This finding directly contradicts the DOE CWG report's conclusions across multiple metrics including record-breaking temperatures, days above 95°F, and number of heatwave days.

Global Context: Expanding the analysis beyond the continental U.S. to northern hemisphere mid-latitudes demonstrates a clear warming trend, with the last decade consistently showing higher temperatures than the 1930s across most regions. This broader perspective reveals that focusing solely on the U.S. obscures the global warming signal. **They should acknowledge that their analysis is built on cherry picking and report results for larger regions, as we did in this comment.**

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Data Access:

Code to reproduce the figures can be found [here](#). The Berkeley Earth data are found [here](#). USCRN data used in the DOE CWG report are found [here](#).

Response to Chapter 6, Section 6.4: Extreme Precipitation

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This section of the DOE CWG report focuses on the author's analysis of extreme precipitation trends across a subset of stations in a few regions of the continental U.S. We note that extreme precipitation is of interest in the physical climate system since increases in the heaviest downpours are expected to occur in a warming climate, a longstanding prediction that has been borne out observationally (e.g., Westra et al., 2013, 2014; Fischer and Knutti, 2016; Dong et al. 2020; Paik et al., 2020; Fowler et al., 2021; Sun et al., 2021). This is because more water vapor can be present in a warmer atmosphere (at approximately the Clausius-Clapeyron scaling of $7\% \text{ K}^{-1}$), far greater than changes in *average* precipitation. This upper bound on water holding comes into play in extreme events where water is converging into a region and a "parcel" of air empties all of its moisture. Nonetheless, this statement is sensitive to the time horizon considered (e.g., hourly vs 1-day vs 5-day) and it is not true at the level of every weather station (especially since extreme events are rare by definition) and a larger spatial scale is required to isolate the signal-to-noise ratio for detecting climate change effects. In this section, the authors only consider 3-day and 5-day rainfall records, which does not cover the complete picture of risk in extreme events, for example with flash flooding. Below, we highlight these and other specific issues of the DOE CWG section 6.4.

Page: 60, Box: Perils of short data record

Comment Type: Reference

Comment:

Porter et al (2011) is a 200-page document on hypothetical megastorm scenarios designed to improve hazard preparedness. The authors of the DOE report are referring to one sentence (p. 2) which states that there is geological evidence of six megastorms that caused large floods prior to European settlement. Porter et al. assert that the

1861-62 storms were “probably not the worst” and then refer to the sedimentary layers indicating these six past megastorms. Porter et al. do not provide any quantitative indication of the intensity of these storms. Therefore, the claim that “Porter et al. (2011) discovered that in the past 1,800 years at least six megastorms were more intense than the devastating 1861-62 ARkStorm” is not supported by Porter et al. (2011).

Page: 61

Comment Type: Reference

Comment:

The literature regarding rainfall trends are all self-citations (except for the NCAs which are used to introduce the topic). The report authors do not reference any of the published peer-reviewed literature on the topic, of which there is plenty.

Other studies cited by the National Climate Assessment and IPCC using all the available information find increasing trends across most of the CONUS in most seasons (e.g. Kunkel et al., 2020; Kirchmeier-Young & Zhang, 2020; Dunn et al., 2020; Sun et al., 2021)

Page: 61

Comment Type: Technical

Comment:

“Interestingly, the regional variations indicate that the largest increases in extreme precipitation events are in the Northeast and the smallest in the West, a pattern counter to the changes in temperature extremes”

It is unclear what point the authors are trying to make here. Precipitation extremes and temperature extremes are caused by different physical mechanisms, so it is not expected that local extreme precipitation trends will follow local extreme temperature trends.

Page: 62, 63, Figure 6.4.1- Figure 6.4.3

Comment Type: Technical

Comment:

In their analysis, the report authors average over 29 stations on the Pacific coast to conclude there is no tendency for extreme precipitation events to become more frequent over time. They conclude the same from 24 southeast and 27 northeast stations, at least when averaging over all stations in the analysis. Of the more than 2000 weather stations in the US, they use approximately 80. Although the authors did not cherry-pick these stations, it still undersamples spatially. Jorgensen & Nielsen-Gammon (2024) noted this in reference to the southeast domains, referring to McKittrick & Christy, (2019): "The majority of these stations happen to be located in those parts of Mississippi, Alabama, Georgia, and northern Florida where the historic trends are relatively weak and nonexistent, and none of them are in the parts of Texas, Louisiana,

and North Carolina with the largest trends.” Sun et al.(2021) also show that over North America, there is clearly a larger number of station-level increases than decreases in maximum amount of precipitation accumulated over 1 day (Rx1day) and 5-day (Rx5day) precipitation, although it is true that the western part of the country exhibits a different pattern. We also note that extreme precipitation evaluation is sensitive to the metric of extremeness. For example, Jorgensen & Nielsen-Gammon showed that daily rainfall intense enough that it only has a 1% chance of happening in any given year has markedly increased in the southeastern US. For the Pacific region, given that we expect latitudinal changes in Atmospheric River landfalling (e.g. Payne & Magnusdottir, 2015; Shields & Kiehl, 2016), averaging over all stations may lead to weak trends because some locations may experience increasing trends while others experience decreasing trends.

Page: 62

Comment Type: Reference

Comment:

See previous Porter comment.

The reference to the six previous megastorms and the 19th century ARkStorm are examples of cherry-picking. While the 1861-1862 event was significant, there have been plenty of impactful Atmospheric River events since which are ignored by the report. For example:

- December, 2010, parts of California received 250-670mm (10-26 in.) (Ralph & Dettinger, 2012).
- May, 2010, Nashville received 344.7mm of rain in 2 days and 11 people died (Moore et al, 2012).
- The 2017 Oroville Dam Spillway Incident (Henn et al, 2020).
- January 2021, Big Sur landslide (Zou et al, 2023).

Page: 62

Comment Type: Technical / response

Comment:

The authors select the 26 wettest 5-day intervals, which they consider to represent a one-in-five-year event. This would be the case if they were looking at only the wettest 5-day period in each year (or, as is often more appropriate, each season), in which case the events can be assumed to be essentially independent. However, it's not clear if consecutive very wet days – or wet days at multiple neighbouring stations simultaneously – have been declustered or simply treated as if they were independent observations. Without such declustering, very large storms will appear in the sample multiple times, introducing biases towards years with such events.

The report authors claim that 'if there are no trends in precipitation, then the total number of these events across all stations should be evenly spread over the years'. However, this part of the analysis has not looked at trends in precipitation volumes, only

counted exceedances (possibly including clusters of exceedances) of a high threshold. Long-duration events like these are expected to be strongly affected by changes to the dynamic component of precipitation i.e. where are the weather systems and do they stall (Pfahl et al, 2017), which is dominated by natural variability. Furthermore, when events are pooled indiscriminately in this way without considering whether they are likely to arise from the same dynamical physical processes (e.g. hurricanes, severe thunderstorms, fronts, atmospheric rivers), potentially meaningful trends in subsets of the data can be masked. The lack of an identifiable trend in this analysis is therefore not surprising.

This is an unusual approach with no cited basis in the literature other than self-citation, and no written justification. There is also only one metric used, which means it is impossible to tell how the results are sensitive to the choice of metric used.

Page: 64

Comment Type: Technical

Comment:

"We use 3-day totals here as this produced the largest temporal variations in time."

There are two possible interpretations of this remark, and it's not clear which is intended by the authors. The 'largest temporal variations in time' may mean the strongest trend (i.e. the largest variation in the mean trend over time); however, it may also mean that the variability (noise) in the time series was larger. For either interpretation, it's concerning that the authors change their analysis method without properly discussing the sensitivity of the results to the length of accumulation studied.

Page: 65, Figure 6.4.5

Comment Type: Technical

Comment:

It's not clear why the authors only present changes in average rainfall per event for one region. The caveats discussed above concerning the possible double-counting of large events, and treating events that occur in different seasons and regions, without accounting for prevailing modes of climate variability, as if they are part of a homogeneous population, apply here also. The authors refer to Figure 6.4.5 (average precipitation per event) in support of their finding that there was no regional pattern in the number of events, although Figure 6.4.5 says nothing about the frequency of events.

Page: 63-65

Comment Type: Technical

Comment:

There are several key weaknesses of this method beyond those already highlighted:

- The analysis studies change over time, rather than changes with greenhouse gases or global warming, as established attribution methods do. That means that the natural variability expected in the 19th and early 20th centuries, when human

influence was relatively small, could hide the more recent strong trends as the world has warmed.

- The analysis does not account for the effects of internal climate variability, which can mask trends. This was used as a criticism of extreme event attribution by the authors in section 8.6 (p. 95).
- Many of the conclusions in the section are drawn from a visual inspection of the time series presented. This is not a scientifically robust approach.
- The authors rely solely upon statistical significance to determine whether a trend, and (by their implication) climate change influence, is present in the data. The American Statistical Association Statement on p-Values (i.e. statistical significance) warns that: 'Scientific conclusions and business or policy decisions should not be based on only whether a p-value passes a specific threshold' (Wasserstein & Lazar, 2016). Statistical significance alone cannot prove nor refute the cause of a trend or lack thereof.

Page: 66

Comment Type: Reference

Comment:

“Jong et al. examined CMIP6...fewer such systems in the 21st century...This conjecture is not seen in Fig 6.4.5.”

Figure 6.4.5 presents data from 1890-2024, which is predominantly the 20th century. It therefore cannot be used to refute projections of changes that are expected to occur in the 21st century, in a further warming climate. Furthermore, it's likely that the data represented in Figure 6.4.5 combines precipitation from hurricane and non-hurricane events with rainfall driven by other processes, which may exhibit different trends. A more careful analysis would be required to understand how rainfall associated with particular circulation patterns and weather types is changing. Furthermore, they claim that the amount per event has remained steady over the 135-year period but previously referred to a weakly increasing trend. Furthermore, the Jong et al. reference cited by the DOE CWG document, in its very first sentence (and echoed throughout the paper), states: “The Northeast United States (NEUS) has faced the most rapidly increasing occurrences of extreme precipitation within the US in the past few decades.” Many other papers also demonstrate this (e.g., DeGaetano et al., 2020).

Page: 66, summary paragraph

Comment Type: Technical

Comment:

The authors conclude that the claim that extreme short-duration rainfall events are becoming more frequent or intense is not supported by their results. However, their analysis examined 5-day and 3-day rainfall totals over a fraction of the US. They do not present results on short-duration rainfall (usually considered to be less than 1-day) and therefore cannot draw conclusions about short-duration rainfall from their analysis. Finally, as discussed above in the comment on Figure 6.4.1, characterising the small

number of stations analysed here as providing ‘nationwide’ coverage is extremely misleading, and to extrapolate from such a limited analysis to statements about trends over the whole of the United States is scientifically indefensible.

To address these comments, the following changes must be made:

- Summarize peer-reviewed literature beyond the authors’ own work on extreme rainfall trends.
- Expand the number of stations analyzed to incorporate a broader spatial domain.
- Expand the extreme rainfall metrics used to include short-duration rainfall extremes and to explore the sensitivity of the results to the choice of metric.
- Revise the trend attribution method to account for natural variability and test whether extreme rainfall changes with a direct indicator of greenhouse gases or global warming such as temperature or CO₂.

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Response to Section 6.5 Tornadoes

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Summary

In Section 6.5, Tornadoes, the DOE CWG report misquotes Intergovernmental Panel on Climate Change (IPCC) AR6, and omits key findings on increased variability, eastward shifts, and winter clustering of tornadoes. Recent peer-reviewed studies confirm these changes and their implications for rising risk in more vulnerable regions. DOE should correct its AR6 citation, incorporate the full body of evidence, and revise its conclusions to reflect observed variability and shifting tornado distributions.

Comment 1.

Page: ix

Comment Type: Technical

Comment: The DOE CWG executive summary states increased frequency of tornadoes are “...not supported by U.S. historical data.” This statement is missing nuance. As detailed in comments 2 and 3 below, observational data indicate tornadoes have clustered into larger outbreaks and have shifted eastward and increased over the Southeast U.S. in the winter.

Action: The DOE CWG authors should revise this sentence after a more rigorous assessment of the observational data and relevant scientific literature (see also action items in comments 2 and 3 below).

Comment 2.

Pages: 66-67, Figure 6.5.1

Comment Type: Technical

Comment: The authors of the DOE CWG report selectively quote chapter 11 of the IPCC Sixth Assessment Report (AR6; Seneviratne et al. 2021). The two sentences they quote are on page 1595, not 1594 as mentioned in the DOE CWG report. Moreover, the second sentence is only partially quoted. The full statement on observational trends in AR6 is below. The part in bold was left out of the DOE CWG report.

“...observational trends in tornadoes, hail, and lightning associated with severe convective storms are not robustly detected due to insufficient coverage of the long-term observations. There is medium confidence that the mean annual number of tornadoes in the USA has remained relatively constant, **but their variability of occurrence has increased since the**

1970s, particularly over the 2000s, with a decrease in the number of days per year, and an increase in the number of tornadoes on these days (high confidence)."

The part in bold is a significant omission. An increase in the variability was observed by Brooks et al. (2014), and this continues to be found in the literature (Tippett et al. 2016; Graber et al. 2024). Figure 1b from Graber et al. (2024) is reproduced below.

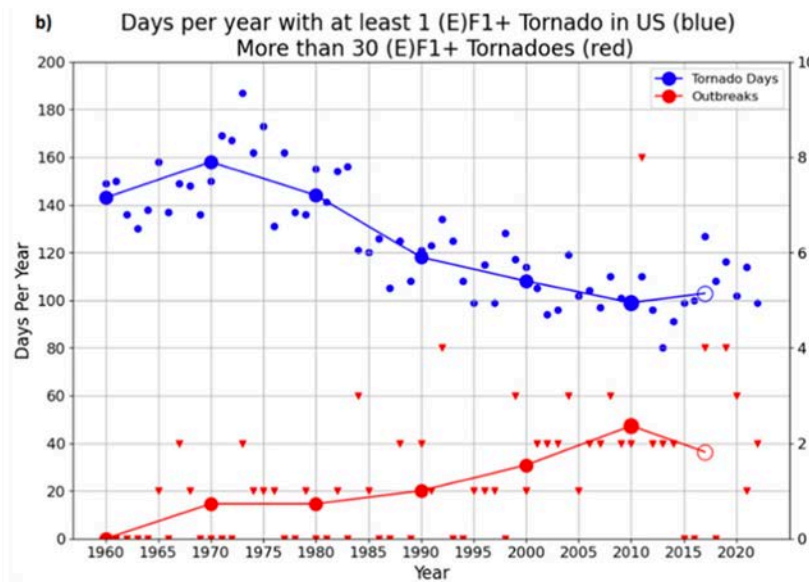


Figure 1b from Graber et al. (2024).

Action: The DOE CWG authors need to fully quote AR6 to include the observed increase in variability with tornadoes clustering into larger outbreaks.

Comment 3.

Pages: 66-67

Comment Type: Technical

Comment: The authors of the DOE CWG report omit how tornadoes have shifted eastward to become more common in the Midwest and especially the Southeast in winter. AR6 states on page 1595:

“There has been a shift in the distribution of tornadoes, with increases in the mid-south of the USA and decreases over the High Plains (Gensini and Brooks 2018).”

Recent analyses of both tornado data and tornado-favorable environments have confirmed this eastward and winter shift (Coleman et al. 2024; Graber et al. 2024; Strader et al. 2024). While a direct link from tornadoes to anthropogenic climate change has not been established, these regional trends are consistent with modeling studies showing severe thunderstorms in general shifting systematically eastward and earlier in the season in a warmer world (Ashley et al. 2023), suggesting that this link is plausible. Southeast tornadoes more frequently occur at night and

hence are much deadlier because people are less likely to take shelter (Strader et al. 2022). Moreover, the increase in tornado days over the Mid-South region coupled with societal exposure changes has increased the housing exposure threefold since 1980 (Strader et al. 2024).

Action: The DOE CWG authors need to include the observed shift in distributions of tornadoes and cite the relevant literature that has been published since AR6.

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Section 6.6: Flooding

Edited by A.E. Dessler, Texas A&M University

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6.6.1 Summary

The assessment relied solely on the IPCC AR6, taking quotes out of context, and an outdated national climate assessment report (NCA4 instead of NCA5). It moreover failed to include any of the peer-reviewed studies on climate change and flooding.

The organization of this section is as follows: Section 6.6.2 reviews what the DOE CWG report did say followed by comments on what was not correct, left out, or otherwise lacking and what is needed to reconcile. Then section 6.6.3 summarizes best available science that the DOE report should have included in order for it to be a complete and unbiased summary of observations and projected climate change impacts on flooding. This revision should specify the different contributors to flooding, including the different ways that climate change can affect flooding (see section 6.6.3), such as highlighted by the 5th National Climate Assessment:

“Precipitation changes do not have a one-to-one relation with flooding. Many factors influence floods, including short- and long-term antecedent moisture conditions, presence of frozen soils, snowpack accumulation, rain-on-snow events, storm tracks, and rainfall rates.” (NCA5, USGCRP 2023).

6.6.2 Addressing Each Statement in the DOE CWG Report

Comment 1.

Page Number in DOE CWG Report: 67

Statement in DOE CWG Report (bolded and italicized text is kept as in the report):

“AR6: **The SREX assessed *low confidence* for observed changes in the magnitude or frequency of floods at the global scale.** This assessment was confirmed by the AR5 report. The SR15 found increases in flood frequency and extreme streamflow in some regions, but decreases in other regions. . . [H]ydrological literature on observed flood changes is heterogeneous, focusing at regional and sub-regional basin scales,

making it difficult to synthesise at the global and sometimes regional scales. (Chapter 11.5)”

Comment type: technical

Comment: As stated in the second part of the quote from AR6, it is difficult to synthesize flooding changes at the global scale due to the heterogeneity of scales being observed. Indeed, as with drought (see response to Section 6.7), flooding is heterogeneous, and therefore climate change impacts on flooding are also heterogeneous (NCA5). Within the U.S., multiple regions have experienced an increase in peak streamflow and flooding, including the eastern Dakotas (NCA5, 25-10), the Central U.S., and the Northeastern U.S. (Davenport et al., 2021; Mallakpour and Villarini, 2015).

Comment 2.

Page Number in DOE CWG Report: 67

Statement in DOE CWG Report (bolded and italicized text is kept as in the report):

“AR6: [T]he seasonality of floods has changed in cold regions where snowmelt dominates the flow regime in response to warming (*high confidence*). Confidence about peak flow trends over past decades on the global scale is **low**. (Chapter 11.5)”

Comment type: reference

Comment: The citation from AR6 leaves out the second part of the statement (underlined), that points to regional differences in flooding related to runoff. Notably, the rest of the statement identifies the north-East US as a place where such flooding has *increased*:

“In summary, the seasonality of floods has changed in cold regions where snowmelt dominates the flow regime in response to warming (*high confidence*). There is *low confidence* about peak flow trends over past decades on the global scale, but there are regions experiencing increases, including parts of Asia, Southern South America, north-east USA, north-western Europe, and the Amazon, and regions experiencing decreases, including parts of the Mediterranean, Australia, Africa, and south-western USA.”

Comment 3.

Page Number in DOE CWG Report: 68

Statement in DOE CWG Report (bolded text is kept as in the report):

“NCA4: Trends in extreme high values of streamflow are **mixed** across the United States. Analysis of 200 U.S. stream gauges indicates areas of both increasing and decreasing flooding magnitude **but does not provide robust evidence** that these trends are attributable to human influences (pp. 240-241).”

Comment type: technical, reference]

Comment: Flooding is highly linked to precipitation patterns and extreme events, which is observed (see e.g. Figures 7.1-7.4 in the USGCRP 2017 report and referenced literature therein (Easterling et al. 2017)) and projected (Figures 7.5-7.8 in the same report) to change across most of North America (also see our comments to section 6.4 of the CWG report). Another important factor influencing flooding is sea level rise, which is commented on in our response to Chapter 7 of the CWG report.

Due to the complexity of factors and regionality of what controls the severity and frequency of flooding, it is necessary to provide a more nuanced and comprehensive report of observed and projected changes. The lack of robust evidence that flooding trends are attributable to human influence stems from this complexity and heterogeneity across regions and scales, but it does not change the fact that the patterns are changing. From the USGCRP 2017 report, p. 241 (Wehner et al. 2017) - reference numbers in citation are from the USGCRP report:

“Recent analysis of annual maximum streamflow shows statistically significant trends in the upper Mississippi River valley (increasing) and in the Northwest (decreasing).⁴⁴ In fact, across the midwestern United States, statistically significant increases in flooding are well documented.^{78, 82, 83, 84, 85, 86, 87, 88} These increases in flood risk and severity are not attributed to 20th century changes in agricultural practices^{87,89} but instead are attributed mostly to the observed increases in precipitation shown in Figures 7.1 through 7.4.^{78, 84, 89,}⁹⁰ Trends in maximum streamflow in the northeastern United States are less dramatic and less spatially coherent,^{44, 80} although one study found mostly increasing trends⁹¹ in that region, consistent with the increasing trends in observed extreme precipitation in the region (Ch. 6: Temperature Change).^{34, 80}”

Further, pulling only from NCA4 when there is a more recent National Climate Assessment available (NCA5) is not appropriate. Indeed, many flooding attribution studies in the US were published between NCA4 and NCA5 (see section 6.6.3). In NCA5:

“Many other extremes, including heavy precipitation, drought, flooding, wildfire, and hurricanes, are becoming more frequent and/or severe, with a cascade of effects in every part of the country” (NCA5, p.1-16).

Comment 4.

Page Number in DOE CWG Report: 68

Statement in DOE CWG Report:

“The absence of detectable US-wide trends in flooding is consistent with the findings in Section 6.4 of absence of coherent changes in extreme precipitation.”

Comment type: technical

Comment: There have indeed been detectable trends in flooding across the US (see comment 3 above), stemming from (a) increased extreme precipitation, (b) earlier snowmelt, and (c) storm surges. Climate change has contributed to some of these flooding trends and events (see

section 6.6.3). There is confidence in trends in increased extreme precipitation for certain regions of the US (see references in section 6.6.3).

6.6.3 Synthesis of Literature Based on Best Available Science

Climate change can exacerbate flooding in different ways, including via sea level rise and storm surges, hurricanes, rapid and early snowmelt, and heavy precipitation events.

While sea level rise is discussed in a different section (Chapter 7), it is relevant for flooding in coastal regions. Sea level rise can contribute to flooding when coupled with storm surges and high tide events (e.g., [Sweet](#) et al. 2018; [Wdowinski](#) et al. 2016; [Gori](#) et al. 2022). Furthermore, there has been an increase in hurricane-related damages over time ([Grinsted](#) et al. 2019), and hurricanes have started to reach further inland and move more slowly ([Li](#) and Chakraborty 2020). Flooding from Hurricane Harvey is shown to be partially attributable to climate change (Wehner and Sampson 2021; Smiley et al. 2022).

Furthermore, in mountainous regions of the western US, climate change leads to a shift from snow to rain, earlier snowmelt, and rain-on snow events ([Marvel](#) et al. 2021; Lynn et al. 2020; McCabe and Clark 2005; McEvoy and Hatchett 2023), all of which can lead to flooding (e.g., Henn et al. 2020).

Finally, extreme precipitation can lead to both localized and downstream flooding. Climate change leads to warmer air temperatures, and warmer air can hold more water vapor — this principle has both exacerbated droughts (see drought response, section 6.7) and contributed to heavier precipitation events ([Swain](#) et al. 2025; Mallakpour and Villarini 2015).

There has been an observed intensification of extreme precipitation globally and across CONUS, largely due to more heavy precipitation events (NCA5; [Kunkel](#) et al. 2020; [Dunn](#) et al. 2020; [Papalexiou and Montanari 2019](#)), with flooding downstream (Mallakpour and Villarini 2015), and climate change contributed to this intensification (Diffenbaugh et al. [2017](#), [2018](#); [Kirchmeier](#)-Young and Zhang 2020; [Davenport](#) et al. 2021; Madakumbura et al. 2021). Note that while atmospheric river intensification is projected for California, it is not yet detectable (Williams et al. 2024), as it is currently masked by low precipitation due to natural variability and aerosols (see response to drought section, 6.7). With that said, the intensity of the atmospheric rivers that contributed to the Oroville dam flooding have been partially attributed to climate change (Michaelis et al. 2022).

There is also a projection of further future intensification of atmospheric rivers ([Espinoza](#) et al. 2018; [Huang](#) et al. 2020; [Payne](#) et al. 2020; Baek and Lora 2021) and overall flood risk ([Wahl](#) et al. 2015; [Wing et al. 2022](#)), including megaflood risk in California ([Huang and Swain 2022](#)).

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Section 6.7: Drought

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6.7.1 Summary

The drought section of the DOE CWG report argued that there has been no observed trend in frequency or intensity of ‘drought’. However, this section is misleading. It often relies on a narrow definition of drought (conflating meteorological drought with other types of drought). It furthermore cherry-picks studies and quotes, relying on an outdated synthesis report, quoting sections out of context, and only including *one* peer reviewed study, while failing to reference the abundance of other studies from the rest of the peer-reviewed literature on this subject.

Contrary to what is stated in the DOE CWG report, there has been a proliferation of detection and attribution studies on how climate change has exacerbated drought, both in the US and globally. Many of these studies have been published in the past five years. These studies identify a significant climate change fingerprint on droughts over the past decades, and project more intense and longer duration droughts in the future. Particularly relevant to DOE is the impact of drought on energy demand which is increasingly affected by warmer surface temperature and high atmospheric evaporative demand (AED) over the Western US (e.g., Byers et al. 2020; Turner et al. 2019; Qiu et al. 2023).

The organization of this section is as follows: Section 6.7.2 reviews what the DOE CWG report did say followed by comments on what was not correct, left out, or otherwise lacking and what is needed to reconcile. Then section 6.7.3 summarizes best available science that the DOE report should have included in order for it to be a complete and unbiased summary of observations and projected climate change impacts on drought.

6.7.2 Addressing Each Statement in the DOE CWG Report

Comment 1.

Page number in DOE CWG Report: 68

Statement in DOE CWG Report: “Assessments of drought trends were as follows.”

Comment type: Reference

Comment: This section relies fully on two IPCC-based reports, but takes comments out of context (see comments below), and one out-of-date National Climate Assessment (NCA4, USGCRP 2017) and similarly takes statements out of context (see comments before). However, it does not reference the proliferation of peer-reviewed detection and attribution studies nor projection-based studies that look at drought and climate change (see Section 6.7.3).

Action: The DOE CWG Report authors should edit this assessment by including the Fifth National Climate Assessment (NCA5, USGCRP 2023), providing an *accurate* representation of main-level findings in AR6 (IPCC 2021), SREX (IPCC 2012), and NCA5, and include the peer reviewed studies listed in Section 6.7.3.

Comment 2.

Page Number in DOE CWG Report: 68

Statement in DOE CWG Report: “AR6: Few AR6 regions show observed increases in meteorological drought (Section 11.9, p. 1575)”

Comment type: Technical

Comment: “Meteorological drought” is measured only using precipitation, but does not take into account other changes (e.g. in temperature or evaporative demand) which can lead to or exacerbate drought (see Section 6.7.3). Thus, relying solely on measures of “meteorological drought” to ascertain whether or not drought has become worse is misleading. The DOE CWG report authors would have been aware of this, because in the reference they use here (AR6), it makes this point:

“The assessment is subdivided in three drought categories corresponding to four drought types: i) meteorological droughts, ii) agricultural and ecological droughts, and iii) hydrological droughts... [M]eteorological droughts are assessed based on observed and projected changes in precipitation-only metrics such as the Standardized Precipitation Index (SPI) and Consecutive Dry Days (CDD)” (IPCC AR6 2021, Section 11.9.4, p. 1605).

Action: The DOE CWG report authors should add what AR6 (IPCC 2021) states about agricultural, ecological, and hydrological droughts, as well as the influences of surface temperature, in addition to that of precipitation, on these droughts.

Comment 3.

Page Number in DOE CWG Report: 68

Statement in DOE CWG Report: “NCA4: As a consequence of this increased precipitation, drought statistics over the entire CONUS have declined.”

Comment type: technical & reference

Comment: First, it is misleading to look at spatial averages over all of CONUS when examining drought. While it is scientifically accurate to take large spatial averages of certain variables (e.g.,

global mean temperature, global atmospheric CO₂ concentrations, etc), drought is an inherently local and regional phenomenon, as evidenced by the different trends observed in the Palmer Drought Severity Index (PDSI) during the last 50 years over the western US (WUS) and eastern US (EUS) (Figure 1). PDSI is a commonly used measure of drought (see section 6.7.3). With the observed increase in intensity of drought over the WUS, and with the increase in extreme flooding and precipitation events over the EUS (see response to Section 6.6), taking an average across the CONUS runs the risk of averaging out these trends (see Section 6.7.3). Indeed, effects of these droughts have been seen in the WUS, especially with groundwater running dry in part due to climate change (Liu et al. 2022; Chandanpurkar et al. 2025; see section 6.7.3).

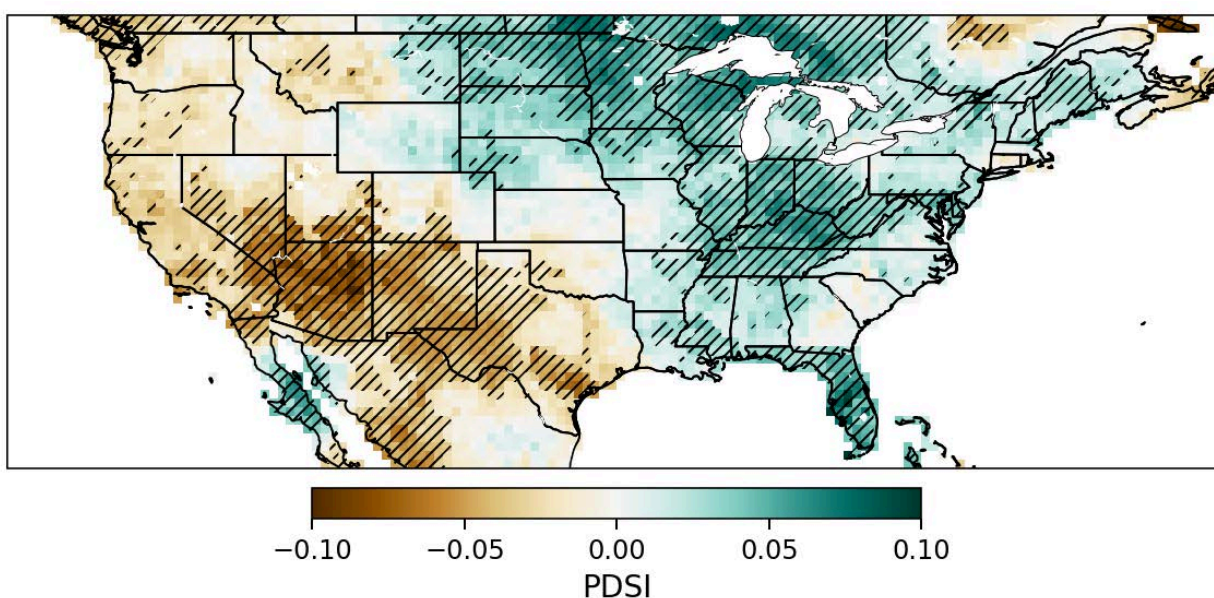


Figure 1. Annual self-calibrated Palmer Drought Severity Index trends from 1974-2023 (Barichivich et al. 2024). Trends were computed using a Theil-Sen estimator. Areas hatched are statistically significant based on Kendall's τ statistic ($p < 0.05$).

Second, this quote is taken out of context, as that section from NCA4 (USGCRP 2017) explains how climate change can exacerbate droughts in the US (DOE CWG report quote bolded):

“Drought is, of course, directly connected to seasonal precipitation totals. Figure 7.1 shows detectable observed recent changes in seasonal precipitation. In fact, the increases in summer and fall precipitation are at odds with the projections in Figure 7.5. **As a consequence of this increased precipitation, drought statistics over the entire CONUS have declined**^{3,12}. Furthermore, there is no detectable change in meteorological drought at the global scale. However, a number of individual event attribution studies suggest that if a drought occurs, anthropogenic temperature increase can exacerbate soil moisture deficits... [T]able 8.1 summarizes available attribution statements for recent extreme U.S. droughts. Statements about meteorological droughts are decidedly mixed, revealing the complexities in interpreting the low tail of the distribution of precipitation. Statements about agricultural drought consistently maintain a human influence if only surface soil moisture measures are considered.”

Third, as this statement is largely in context of, again, *meteorological* drought, it would make sense to examine figure 7.1 in NCA4 (USGCRP 2017). Figure 7.1 in NCA4 is depicting observed changes in precipitation over the United States between the ‘early period’ (1901-1960) versus ‘present day’ (1986-2015) (USGCRP 2017, p. 209). Notably, while the figure shows increases in precipitation for some regions of the country, for much of the WUS, in the seasons where most precipitation falls (late fall, winter, and early spring), there are declines in precipitation. See Section 6.7.3 for a description of how observed *decreases* in precipitation over the southwestern US are linked to a combination of natural variability and aerosol-driven changes.

Finally, this reference is outdated. While the 4th National Climate Assessment (NCA4) represented the best available science at its time of publication in 2017, it was not the most recent national climate synthesis report available when the DOE CWG report was written, as the 5th NCA (USGCRP 2023) was published in 2023.

Action: To address this comment, the DOE CWG report authors should reference what the *5th* National Climate Assessment (NCA5, USGCRP 2023) has to say about drought instead of the 4th, and moreover provide a review of what NCA5 stated about each type of drought (meteorological, agricultural and ecological, and hydrological).

Comment 4.

Page Number in DOE CWG Report: 68

Statements in DOE CWG Report:

“NCA4: Recent droughts and associated heat waves have reached record intensity in some regions of the United States; however, by geographical scale and duration, the Dust Bowl era of the 1930s remains the benchmark drought and extreme heat event in the historical record (very high confidence).”

“SREX (IPCC 2012): From a paleoclimate perspective, recent droughts are not unprecedented, with severe ‘megadroughts’ reported in the paleoclimatic record for Europe, North America, and Australia. (p. 170)”

Comment type: technical

Comment: First, just because there have been more severe droughts in the historical record does not mean that climate change did not make recent droughts worse. A different ‘flavor’ of droughts now develop that are exacerbated by climate change, largely due to increased atmospheric evaporative demand (AED) (see Section 6.7.3; e.g., Zhuang et al. 2024; Williams et al. 2020; Weiss et al. 2009). The inverse is also true: the fact that climate change is making droughts worse does not mean that today’s droughts are worse than any in the historical record.

Second, just because there have been more severe droughts in the historical record does not undo the fact that recent droughts have had profound consequences (Smith 2020).

Third, research has indicated that recent droughts in the WUS were more severe than droughts over the past 1000+ years: while megadroughts have occurred in the paleoclimatic record, the western US megadrought of 2000-2018 was the worst since the mid-1500 (Williams et al. 2020) and from 2000-2021 was the worst since 800 (Williams et al. 2022) as defined using soil moisture anomalies. Similarly, climate change made the 2012-2014 period in CA the driest period in 1200 years (Griffin and Anchukaitis 2014; Williams et al. 2015).

Finally, climate projections indicate that for regions plagued by drought (e.g., western US), future droughts will be even more severe (see Section 6.7.3; e.g., Naumann et al. 2018; Gebrechorkos et al. 2025; McEvoy et al. 2020; He et al. 2021).

Action: The DOE CWG report authors should describe how recent droughts of the past few decades compare to droughts in the historical record, specifically explaining the balance of AED-driven versus precipitation-driven droughts, include projections of western US drought for later this century, and at least mention the consequences of these droughts.

Comment 5.

Page Number in DOE CWG Report: 68

Statement in DOE CWG Report: “As shown in Figure 6.7.1, U.S. long-term data shows an insignificantly declining trend in extreme dryness (-0.001 percent per year)”

Comment type: technical

Comment: Figure 6.7.1 in the DOE CWG Report depicts the percent of CONUS that is “very dry”, defined as being < 10th percentile for precipitation. There are three scientific inaccuracies in relying on this figure to interpret a presence or absence of drought trends in the US:

1. It is misleading to look at an averaged value of any drought metric over all of CONUS, because there are different patterns across the region, with generally more intense precipitation observed in the eastern US with more drought in the western US (Figure 1; Section 6.7.3).
2. This figure is only based on precipitation. If ‘very dry’ instead was measured by soil moisture, streamflow, or other similar indicators, the figure would look different (e.g., Williams et al. 2020, 2022; Williams et al. 2024; Diffenbaugh et al. 2015; Gebrechorkos et al. 2025).
3. The trend line is based on monthly data from 1895-2025. However, this is misleading because it ignores recent trends in regional, AED-driven droughts that have been exacerbated by climate change (e.g., over Southwestern North America; Cook et al. 2021; Williams et al. 2020, 2022).

Action: To address this comment, the DOE CWG report authors should provide a spatial analysis of trends (e.g., Figure 1) or separate time series for different regions of the US (regions used by the US Drought Monitor: <https://droughtmonitor.unl.edu/CurrentMap.aspx>). Furthermore, the authors should present any analysis of drought using a well-accepted metric

(e.g., SPEI or PDSI), or at the very least a time series of AED (ideally of VPD or reference evapotranspiration) in addition to precipitation.

Comment 6.

Page Number in DOE CWG Report: 69

Statement in DOE CWG Report: “Kogan et al. (2020) examines a 38-year high-resolution satellite-based drought measure and concludes that global drought has not intensified and is not connected to climate change: “it is possible to state firmly that global and main grain countries’ drought area and intensity trends have not been following global climate warming since 1980’s.””

Comment type: technical & reference

Comment:

There are a plethora of different studies that conclude that droughts *have* intensified around the world (Zeng et al. 2023; Vicente-Serrano et al. 2022) and that this intensification is at least in part due to anthropogenic climate change (e.g, Gebrechorkos et al. 2025). Importantly, rather than the entire globe uniformly having an increase in drought, there are instead regional patterns where for some regions droughts have become more intense while for others flooding has become more intense (see Sections 6.6 and 6.7.3). Moreover, other studies have shown that drought has intensified over the western US due to climate change (Williams et al. 2020,2022; see Section 6.7.3). All of these studies were available at the time of writing the DOE CWG Report.

Furthermore, the approach by Kogan et al. (2020) in taking spatial averages across hemispheres and countries, unfortunately averages out the drought trends that have occurred. Kogan et al. (2020) looked at trends by hemisphere and by country, which, as expected, would suggest little change in drought due to the spatial averaging across regions with strongly different patterns in drought indices (see Section 6.7.3 for problems in taking spatial averages over CONUS for interpreting drought). Indeed, a more recent study that, like Kogan et al. (2020), also looks at a satellite-based vegetation health index for use in drought monitoring (Zeng et al. 2023) identifies how certain areas of the world experience increased drought while others experience decreased. Regions experiencing increased drought include the western US, while the southeastern US shows some improvement.

Action: To address this comment, the DOE CWG report authors should provide a comprehensive and unbiased review of peer-reviewed studies that have examined climate change and observed drought, particularly studies on the US, in order to respond to the mandate of this report. Please see Section 6.7.3 for a more comprehensive literature review.

Comment 7.

Page Number in DOE CWG Report: 69

Statement in DOE CWG Report: “In summary there is no evidence of increasing meteorological drought frequency or intensity in the U.S. or globally over recent decades.”

Comment type: technical

Comment: First and foremost, this statement is misleading. For a section about drought, the focus should be on drought as a whole, not just meteorological drought. As explained in Section 6.7.3, there is both evidence of increasing frequency and severity of droughts of different types in the US and globally, and evidence that some of this increase is due to anthropogenic climate change. This is moreover misleading as earlier in this section in the DOE CWG report (p.68), the authors quote the following from AR6 (IPCC 2021), which is missing from their “in summary” statement:

“AR6: Increasing trends in agricultural and ecological droughts have been observed on all continents (medium confidence), but decreases only in one AR6 region (medium confidence). Increasing trends in hydrological droughts have been observed in a few AR6 regions.”

The statement is also inaccurate as it is not reflective of the best available science which was available at the time of writing of the DOE CWG report. In the WUS, while natural variability explains much of the low precipitation (i.e. meteorological drought) over the past few decades, recent studies suggest that aerosol emissions (emissions associated with fossil fuel combustion in lieu of scrubbers on smokestacks) explain some of the decrease (Kuo et al. 2023; Risser et al 2024).

Action: Given that this statement is likely intended to provide a summary of this section, the DOE CWG report authors should revise this statement to:

“In summary, while there is some limited evidence that climate change has contributed to meteorological drought intensity over the western US, there is strong evidence that climate change has contributed to hydrological, ecological, and agricultural drought in the western US and other regions around the world over the past few decades.”

Comment 8.

Page number in DOE CWG Report: 69-70

Statement in DOE CWG Report: The DOE CWG Report is largely missing a discussion of changing aridity and desertification, which is highly relevant for both drought (this section) as well as for natural and managed ecosystems. There is a single mention on Page 6, section 2.1.3 where the authors assert that aridification of drylands is not an issue, based on a single study by Zhang et al. (2024) that notes due to increased CO₂ levels “increasing aridity in drylands won’t lead to a general loss of vegetation productivity”.

Comment type: technical

Comment: Studies have shown that, globally, climate change has contributed to the desertification of drylands (Burrell et al. 2020) and expansion of dryland (i.e. conversion of humid to dryland area) (Koppa et al. 2024). Other studies project this will continue, with future aridification and dryland expansion projected particularly for regions that are already semi-arid (Huang et al. 2016), including the Mediterranean and North African Regions (Carvalho et al. 2022; Lickley and Solomon 2018; Seager et al. 2014) and the western US (Lickley and Solomon 2018; Udall and Overpeck 2020). This has important implications for drought and vegetation productivity (e.g., Cao et al. 2022). Regarding the response of vegetation productivity to aridification and dryland expansion, please see response to Section 2.1.

Action: We recommend that the report authors summarize research on climate change and broader aridification and desertification in order to better present the current state of knowledge, and outline the existing areas of uncertainty.

6.7.3 Synthesis of Literature Based on Best Available Science

Definitions of and Contributors to Drought

There are a number of different ways to define “drought”, but the most agreed upon way is simply insufficient supply of water to meet demand (USGCRP 2023; Cook et al. 2018). A more specific definition depends on what system you are studying: for example, drought might be defined by insufficient surface water (e.g., in rivers) to meet local demand of cities, or it might be defined by insufficient soil moisture to meet demand of plants in an agricultural land, grassland, or a forest.

There are several definitions of drought which are most commonly used:

- Meteorological drought: Defined as abnormally low precipitation, and measured with indices designed to just look at precipitation (e.g., SPI) (AR6, IPCC 2021, Section 11.9.4, p.1605). *Note, the drought section of the DOE CWG report relied largely on this definition.*
- Agricultural and ecological drought: Defined as insufficient water to meet agricultural or ecological demand (e.g., insufficient water for irrigation, insufficient soil moisture for forests or grasslands, etc.), and often based on measures of soil moisture, water balance (precipitation minus evapotranspiration), and indices designed to measure both (e.g., SPEI, PDSI) (AR6, IPCC 2021, Section 11.9.4, p.1605).
- Hydrological drought: Defined as abnormally low surface water flow and changes in runoff (AR6, IPCC 2021, Section 11.9.4, p.1606).

Therefore, depending on *how* you define drought and what measures you use, you will get different answers to whether drought frequency or severity has changed, whether that change is partially due to climate change, and how it might change in the future (Cook et al. 2018; Mukherjee et al. 2018; Vicente-Serrano et al. 2025). While meteorological drought, by definition, is only influenced by precipitation, agricultural and ecological drought and hydrological drought

are influenced by precipitation, atmospheric evaporative demand (AED), and a number of other complex land surface and even social processes. AED is the evaporative potential of the air (i.e. how “thirsty” the air is) which is a function of temperature and humidity, and AED has increased in many regions of the world, including in the US, largely due to climate change (Albano et al. 2022; Williams et al. 2020, 2022; Williams and Abatzoglou 2025; Gebrechorkos et al. 2025; Vicente-Serrano et al. 2025; Marvel et al. 2025).

Climate Change and Observed and Projected Changes in Drought in the US

Droughts (and flooding, Section 6.6) happen at local to regional scales, and similarly, trends in both are locally- and regionally-specific. Climate change has affected the whole hydrologic cycle, where in certain regions droughts are now more severe and frequent, while in others large flooding events are happening with more frequency and severity. In the US, the *broad, general* trend is that the western US (WUS) has had more droughts, while the eastern US (EUS) has had some drought improvement as well as more floods (with important caveats to each) (Zeng et al. 2023; IPCC AR6 SPM 2021; Herrera et al. 2023; USGCRP 2023).

Western US (WUS)

In the western US (WUS), droughts are geographically larger, longer, more likely, and more intense, partially due to climate-change-driven increases in AED (A.P. Williams et al. 2020, 2022; E.L. Williams et al. 2024, 2025; Zhuang et al. 2021; Zhuang et al. 2024; Diffenbaugh et al. 2015). Moreover, studies suggest that the low precipitation observed over the WUS over most of the past two decades was due to a combination of natural variability and human activities that contribute to climate change: specifically the aerosol emissions (e.g., sulfur dioxide) that have accompanied the burning of fossil fuels (Lehner et al. 2018; Kuo et al. 2023; Risser et al. 2024; Chiang et al. 2021). Therefore, due to climate change, there has been an increased likelihood of hot conditions (and therefore high AED) co-occurring with dry conditions (i.e. low precipitation) (Diffenbaugh et al. 2015; Alizadeh et al. 2020; A.P. Williams et al. 2015).

Due to these mechanisms, climate change has made different types of drought worse in the WUS, and is projected to keep doing so.

Ecological drought. Studies have demonstrated that climate change exacerbated the megadrought of the past two decades (Williams et al. 2020, 2022), resulted in droughts that are more driven by AED than precipitation declines (Zhuang et al. 2024), made the 2012-2014 period in CA the driest period in 1200 years (Griffin and Anchukaitis 2014; Williams et al. 2015), and made it harder to recover from drought once in one (Williams et al. 2024). Climate change is projected to increase the likelihood of extreme multi-year droughts (Cook et al. 2021; McEvoy et al., 2020) and a response in vegetation productivity in response to those droughts (Cao et al.

2022) and the timing of key variables for ecological drought (Marvel et al. 2021), due to increase in atmospheric evaporative demand over the WUS (Gamelin et al. 2022; Ficklin and Novick 2017). Further, projected groundwater declines are anticipated to add to ecological drought risks in high elevation forests (Carroll et al. 2024).

Hydrologic drought. Studies that use measures based on ecological drought are relevant for hydrologic drought as well. In addition, as WUS hydrology is heavily dependent on snowpack and snowmelt (Hale et al. 2023), studies on these variables are also relevant. There has been an observed and projected increase in snow droughts (Cowherd et al. 2023; Huning and AghaKouchak 2020), in part due to a change in precipitation partitioning (i.e. less snow and more rain) (Lynn et al. 2020), with a decrease in overall snow water storage in the WUS (Hale et al. 2023). Studies have shown that climate change has contributed to snow droughts via less snowpack and earlier snowmelt runoff (Gottlieb and Mankin 2024; Shukla et al. 2015; Mote et al., 2018). There are projected future reductions in snowpack, especially later season (April) snowpack which is important for the summer water budget (Siirila-Woodburn et al., 2023; Norris et al., 2025; Marvel et al. 2021). In CA's Central Valley (hosting much of the nation's agriculture), there is a projected continued shift toward earlier streamflow timing, meaning less water available during the hot, dry season (i.e. summer) in the WUS (He et al. 2021). Similarly, groundwater declines in the Upper Colorado Basin are projected to substantially (12-27%) reduce downstream waterflow in addition to projected streamflow loss not accounting for reduced groundwater input (21-81%)(Carroll et al. 2024). Snow-dominated watersheds in the Upper Colorado Basin, Wyoming, and Utah provides nearly 90% of the water to the Colorado River (Jacobs 2011), which supports 40 million people and US\$1.4 trillion in economic activity (James 2014).

Agricultural drought. Climate change has increased the risk of agricultural drought, increasing irrigation demand (or the amount of irrigation that would need to be applied to a field to match AED) (Williams and Abatzoglou 2025) and disrupting snowmelt (see 'hydrologic drought' above), which is a key water supply for agriculture (Qin et al. 2020). Water necessary for irrigation for agriculture will be even further stressed, as WUS agriculture relies heavily on snowmelt (Qin et al., 2020). This has already been observed, with groundwater levels in both California and the WUS in rapid decline (Liu et al. 2022; Chandanpurkar et al. 2025; Perrone and Jasechko 2017; Jasechko and Perrone 2021).

Hydroclimate whiplash. While the WUS has historically had large interannual hydroclimate variability (e.g., Cook et al. 2025), research has indicated that climate change has already increased this variability ("hydroclimate whiplash"; Swain et al. 2025), meaning more dramatic swings from very wet to very dry years, with implications for both drought *and* flooding. Climate change is projected to increase hydroclimate whiplash even more in the future (Swain et al. 2018; Chen et al. 2022).

Eastern US (EUS)

While there is scientific consensus that climate change has increased drought in the WUS, in the eastern US (EUS), this is not the case ([IPCC AR6 SPM 2021, p.10](#)). Although there has been an increase in AED over the EUS due to climate change, this has been masked by changes in precipitation (Williams and Abatzoglou 2025).

Climate Change and Global Observed and Projected Changes in Drought

Globally, there have been more severe droughts due to increased AED (Vicente-Serrano et al. 2025; Trenberth et al. 2014; Gebrechorkos et al. 2025; Vicente-Serrano et al. 2022; Marvel et al. 2025; Li et al. 2024). Moreover, there has been an increase in “flash droughts”, which are droughts that onset or intensify rapidly (Yuan et al. 2023; Christian et al. 2021).

Importantly, this does not mean that *everywhere* has had more droughts, but instead that there has been an increase in drought intensity in many areas around the world. This is, again, because certain areas have both observed and projected intensification of drought due to climate change, other areas do not (or even have the opposite, an increased wetting) (Naumann et al. 2018; Cook et al. 2018; Zeng et al. 2023; Gebrechorkos et al. 2025; Chiang et al. 2021).

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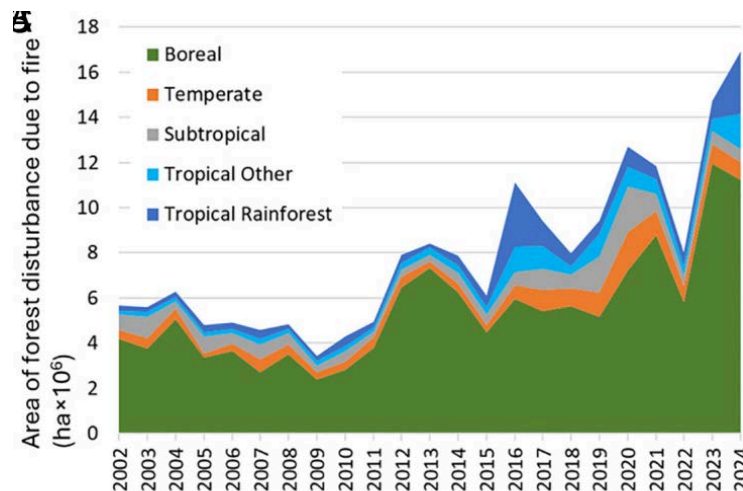
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Comment on Section 6.8, “Extreme weather: Wildfires”

John M. Wallace, Chan-Pang Ng, David Battisti, and Qiang Fu

Section 6.8 (p. 69-71) Wildfires

The discussion in this section relates to forest fires, yet the leadoff graphic (*Fig. 6.8.1*) relates to globally integrated wildfire area, which is dominated by grassland fires set by farmers to clear croplands in the Sahel and its Southern Hemisphere counterpart. The area burned per year has indeed been slowly decreasing in response to improved agricultural practices. While that’s good news, it’s irrelevant to this section, because the global time series shown in this figure bears little relation to the area of forest burned by wildfires. Figure 1A of Potapov et al. (2025) based on forested areas, reproduced here, conveys an entirely different impression.



The statement “Global data show that wildfire coverage is constant or declining on every continent (Samborska & Ritchie, 2024)” on p. 69 is likewise deceptive, because the graphic relates to all wildfires, including those in grasslands and croplands.¹

Citing Cunningham et al. (2024) and Tyukavina et al. (2022), the authors of the DOE Report acknowledge that (in their words), “wildfires are increasing in some parts of the world”. However, they don’t mention that the increases greatly outweigh the decreases, and that the most heavily impacted areas (i.e., the boreal forests and the forests of western US) have experienced a doubling or more of the per year fire-related forest loss over the past 25 years. Nor do they make any mention of the plethora of evidence presented in the literature attributing the worsening wildfire crisis to warming induced by the burning of fossil fuels.

¹ The reference is to the *Our World in Data* website (<https://ourworldindata.org/forests-and-deforestation>), on which a wildfire is defined as “an uncontrolled burn of vegetation, which includes the burning of forests, shrublands and grasslands, savannas, and croplands.”

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Section 6.8: Wildfire

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Summary

The wildfire section of the Department of Energy Climate Working Group (DOE CWG) report focuses on the global decrease in burned area, and trends in US wildfire over the last 1400 and 100 years. The global decline in burned area is driven by land use change in African grasslands, which is not related to greenhouse gas emission impacts, whilst burned area in forested regions – including the US – has increased in recent decades. The subsequent focus on the ‘wildfire deficit’ confounds climate change with changing management practices in the same period. These two lines of investigation are overly specific, do not represent important changes to wildfire in the US or globally, and do not address the extensive scientific literature on the impacts of climate change on wildfire. The likelihood and intensity of the most extreme wildfires has increased in North America, which has had major effects in the western US. These extreme fires have generated substantial ecological, economic, health, and livelihood impacts across the US. The consequences extend far beyond fire-prone regions due to smoke transport across continental distances, exposing populations nationwide to serious health risks. Given both the expanding scope of wildfire impacts and growing public awareness, this topic deserves a clearer and more robust scientific treatment. In the following section, we review each statement in the DOE CWG report and provide corrections, additions, and suggestions for improving the report.

Addressing Each Statement in the DOE CWG Report

Page: Overall comment on Section 6.8, with implications for the entire report.

Comment Type: Technical

Comment: Typically scientific assessments aim to assess the current state of scientific knowledge based on a synthesis of recent scientific literature. Often these assessments use standards to determine the level of agreement/disagreement in the scientific literature and the level of confidence in conclusions that can be drawn therefrom. For example,

Intergovernmental Panel on Climate Change (IPCC) authors assess whether there is limited, moderate, or robust evidence for a scientific conclusion based on the availability of data and papers on the issue. Likewise, they assess the confidence that can be placed on a conclusion based on the volume of evidence and the number of lines of evidence that converge on the conclusion. This section, and most of this report, does not present an assessment of the current state of science. Rather, the authors are making a statement of position and supporting it with selective citations of literature, often with misleading statements. A large body of peer reviewed literature is ignored or key messages from cited papers are not included in the text. For the remainder of the review of this section, we will assume that the authors need to answer the question of how climate change affects wildfire and the impacts of these on human wellbeing.

Comment 1

Page: 69, Paragraph 1 Section 6.8

Comment Type: Technical

Statement: “The IPCC has not provided an attribution assessment of wildfires”

Comment:

Factual errors: While there is no explicit section just on wildfire in the physical science basis 6th assessment of the IPCC report (AR6) (IPCC 2021), there is a review of how climate change has exacerbated fire weather and led to increased burned area (AR6 WGI, Section 11.8.3, p. 1600). Furthermore, there is a section describing how fire weather conditions have increased in the western US, and that this increase is largely due to climate change (AR6 WGI, Section 12.4.6.2, p, 1832). These are both attribution statements. Furthermore, it describes how future climate change is projected to lead to even greater fire weather (AR6 WGI, Section 12.4.6.2, p, 1832). Also, the cross-chapter box #3 in the Special Report on Climate Change and Land (which was part of the AR6 cycle) discusses fire trends and notes the recent increase in W. North America (IPCC 2019). The DOE CWG Report authors need to fix this statement to accurately reflect what the IPCC reports have said about climate change and wildfire.

Since AR6, there have been a considerable number of attribution studies on the response of extreme fire weather to climate change. Since AR6, peer-reviewed studies have demonstrated that climate change has led to increased fire weather (Abatzoglou et al. 2025; Jones et al. 2022, 2024, Turco et al. 2023; Balch et al. 2022; Zhuang et al. 2021; Goss et al. 2020), longer fire seasons (Madakumbra et al. 2025; Swain et al. 2023), and drier fuels (Alizadeh et al. 2021; Ellis et al. 2021; Goodwin et al. 2021). Climate change has led to greater burned area in forests (Abatzoglou et al. 2025; Jones et al. 2022, 2024, Turco et al. 2023) and increased PM2.5 pollution (Burke et al. 2023; Law et al. 2025; Chen et al., 2025) and GHG emissions from fires (Zheng et al. 2021, 2023), and contributed to more intense fires, including the 2025 Los Angeles fires (Barnes et al. 2025).

Action: The DOE CWG Report authors should revise their statement to accurately reflect what the IPCC has said about climate change and wildfires, and include new information from the

above studies in their evaluation of the state of the science regarding climate change and wildfires.

Comment 2

Page 69 Section 6.8 Paragraph 1 and Figure 6.8.1

Comment Type: Technical

Statement: “As shown in Figure 6.8.1, global wildfire activity as measured by the European Space Agency shows a downward trend in the 21st century...Global data show that wildfire coverage is constant or declining on every continent (Samborska and Ritchie, 2024).”

Comment:

Though there has been a decrease globally in fires in savannas (associated with land use change and landscape fragmentation; Andela et al., 2017; Bowman 2020; Zubkova et al., 2023; Jones et al. 2022; Harrison et al., 2025), both burned area and fire carbon emissions have *increased* globally in forested regions (Jones et al. 2022; Jones et al. 2024; Zheng et al. 2021). There has been a large increase in fire activity in the western US (e.g., Weber & Yadav, 2020), and studies have demonstrated that climate change led to an increase in burned area in forested regions of the western US (Abatzoglou and Williams 2016) and in California forests (Turco et al. 2023; Williams et al. 2019).

Action: The DOE CWG Report authors should highlight the clear increasing trends in extreme fire behaviour and fire weather in different regions -- especially in the US and in Canada (due to transported smoke). We would invite the authors to present a more nuanced assessment, as not all continents are exhibiting decreased fire counts or burned area, as observations (Marlon, 2020) and models (the Fire-MIP analysis, e.g. van Marle et al., 2017) both show, and the continental analysis hides, important regional trends.

Comment 3

Page 69 Section 6.8 Paragraph 2

Comment Type: Technical

Statement: “However there is evidence that the intensity of fires in some regions is worsening (Cunningham et al. 2024) and that wildfires resulted in a net loss of global forest cover over 2001-2019 (Tyukavina et al. 2022).”

Comment: This is the only place in which the DOE CWG report authors include attribution studies on wildfire. In addition to these studies, other studies have shown that there has been an increase in extreme fire risk and burned area due to climate change, including in the western US (see comment 1 for a list of these studies). In addition to those studies published since AR6 (again, see comment 1), a number of earlier studies also make this point (e.g., Abatzoglou and Williams 2016; Williams et al. 2019; Kirchmeier-Young et al. 2017; Westerling 2016; Flannigan

et al. 2009), mainly due to increase of surface temperature in spring and summer, and reduced snow cover.

Action: The DOE CWG Report authors should integrate these key studies and their main conclusions into the analysis (i.e. those listed here and in comment 1) for a less partial representation of the peer-reviewed science on climate change and fire.

Comment 4

Page: 69 Section 6.8 Paragraph 3

Comment Type: Technical

Statement: “Marlon et al. (2012) used sedimentary charcoal layers to reconstruct fire history of western U.S. for the past 1400 years and also fit a model to predict fire activity as a function of climatic conditions. Their results are summarized in Figure 6.8.2 below (from Figure 2 in their paper). There has been a growing wildfire deficit over the 20th century. In other words, however much fire was observed in the 20th century, it was less than what would have been observed in previous centuries based on the climatic conditions.”

Comment: The DOE CWG report's summary of Marlon et al. (2012) fundamentally misrepresents the paper's central conclusion regarding the 20th-century “fire deficit.” While the report correctly notes the existence of this deficit, it cherry-picks this single concept while ignoring the explicit causation discussed in the paper. The research clearly attributes the abrupt decline in burning since the late 1800s to the “combined effects of human activities, ecological, and climate changes,” with active fire suppression being a primary human driver. The paper explicitly states: “The divergence in fire and climate since the mid 1800s CE has created a fire deficit in the West that is jointly attributable to human activities and climate change, and unsustainable given the current trajectory of climate change.” In other words, while aggressive fire suppression has, over many decades, led to fuel build-up that contributes to more uncontrollable fires, increasing temperatures from rising greenhouse gas emissions are also exacerbating wildfires, increasing area burned, fire severity, and associated economic costs in the western US.

By stating the deficit arose because 20th-century fire activity was “less than what would have been observed...based on the climatic conditions,” the DOE report inverts the study's finding. It incorrectly implies the climate was less fire-prone than in previous centuries, whereas the analysis shows that humans were both causing climate to become *more* fire prone and also directly suppressing fires *despite* these climatic factors; this combination has led to both a dangerous accumulation of fuel and a more fire-prone climate. The mischaracterization of the research in the DOE CWG report ignores a foundational, long-resolved argument in fire science: that the legacy of suppression has primed forests for more severe fires at the same time that humans are making the climate hotter. The report thus misuses the work to obscure the reality identified: this growing deficit, exacerbated by modern climate warming, is a key reason for the increase in large, high-severity fires today.

Action: The DOE CWG authors should fix this factual error and faithfully represent the findings of Marlon et al. (2012).

Comment 5

Page: 69

Comment Type: Technical

Statement: “Parks et al. (2025) likewise find that despite the recent increase in wildfire burn area in North America, a significant wildfire deficit remains relative to historical wildfire regimes.”

Comment: First, this is misleading as, of course, there is a fire deficit due to the decades of historical fire suppression, and the implication is that even with the climate-fueled increase in severity of fires, fire activity hasn’t yet reached pre-suppression levels (see Parks et al. 2025 Fig. 4). This misrepresents Parks et al. (2025). For instance, they end the abstract by saying: “...there is abundant evidence that unprecedented contemporary fire severity is driving forest loss in many ecosystems and adversely impacting human lives, infrastructure, and water supplies.”

With respect to wildfire deficit, it is true that there is currently still less fire than would be expected based on climate alone; this is due to successful fire suppression in recent decades. Nevertheless, contemporary fires burn at higher severity and intensity than those prior to western settlement. Most of the contemporary burned area occurs when fires evade fire suppression efforts, when fuels are critically dry, and during periods of heightened fire weather. There is widespread evidence of more frequent periods of high fire weather over the past half-century, driven by climate change, across the western US that contributed to the well documented increase in burned area in the western US, particularly in forested areas (Jones et al., 2022; Parks and Abatzoglou, 2020). The DOE CWG authors neglect the recent increase in fire severity and length of fire season in the western US that is largely driven by climate change. They fail to connect climatic changes to the likelihood that wildfire will continue to increase in the western US (and other parts of the globe) and they don’t mention the economic, health, ecosystem service, and ecological costs that we need to prepare for.

Action: The wildfire deficit concept should be accurately described within the broader context of climate change (as explained above) The DOE CWG authors should revise this paragraph to make it scientifically accurate and policy relevant. They can do this by demonstrating that the current trend of increasing wildfire severity is the result of previous fire suppression decisions that led to excessive fuel buildup coupled with increased intensity and duration of fire weather (due to climate change) that exacerbates fuel flammability. This would then support the discussion of wildfire vs. prescribed burning below.

Comment 6

Page: 70, Paragraph 1, Section 6.8 & page 71 Figure 6.8.3

Comment Type: Technical

Comment: The paragraph indicates that fires are not increasing in the US, which is misleading. This paragraph is discussing Figure 6.8.3. In that figure, the data before 1983 should not be compared to the data after 1983, as explained by the source website that data in the graph come from:

“Prior to 1983, the federal wildland fire agencies did not track official wildfire data using current reporting processes. Statistics are subject to substantial changes in what was codified as a wildfire and burned area (e.g., inclusion of incendiary fires plague reporting issues prior to the 1960s, as well as duplicate counting of fires in federal records). As a result, there is no official data prior to 1983 posted on this site.”

The authors also note inconsistencies prior to 1960 in the time series. Instead, looking at the data from 1983-onward (corresponding to when there was consistent data), there is evidence of increased burned area and increased number of very large fires. The section fails to mention that fire is increasing in extent and severity in several regions of the US (see comment 1), boreal North America, and the Arctic with economic impacts on Americans (see comment 7). For example, although the observed wildfire record is short in some regions, Fire Model Intercomparison Project (Fire-MIP) analyses show an increase in extreme events across the boreal region of North America and increasing CO₂ emissions from 1920 to the present day (van Marle et al., 2017). Similar results can be found in several other publications (van der Werf, et al. 2017; McCarthy et al., 2021, etc.). Therefore, a conclusion like “Nonetheless just focusing on the post-1985 interval the number of fires is not increasing” is misleading.

Action: Instead, the DOE CWG report authors should highlight the *robust evidence* that burned area, fire severity, and fire related emissions are increasing across the North American boreal zone, the Arctic, and in the western half of the US (Abatzoglou and Williams 2016; Turco et al. 2023; Williams et al. 2019; Flannigan et al. 2009; Zheng et al. 2023; Kirchmeier-Young et al 2017), and we can draw this conclusion from the scientific literature with *high confidence*. There is enough evidence in the scientific literature to further unpack this conclusion and talk about particulate matter (PM) with a diameter of 2.5 micrometers or less (PM 2.5), black carbon, and other pollutants (e.g., Burke et al. 2023; Law et al. 2025). The authors should include more information on trends in extreme fire driven by the increasing likelihood of extreme fire weather and to report on issues at both a continental and seasonal scale (see comment 1).

Comment 7

Page: 70, Section 6.8, Paragraph 2

Comment type: Technical

Statement: “Forest fires have always been a part of nature, and they can certainly create conditions that are inhospitable in the short term for all life, including humans. Science has confirmed the overall benefit and necessity of forest fires. While recent high-profile fires and seasons serve as a reminder of the potential destructive impact, the highest profile U.S. forest fire remains the 1910 Big Blowup fire in the U.S. west, which destroyed over three million acres and eliminated entire towns like Taft, MT (Apple, 2020). The 1910 fire reshaped the U.S. Forest Service (National Forest Foundation 2022) leading to a focus on fire suppression with a primary

goal of defeating all forest fires (Forest History Society, 2022). This led to the “10 am rule” in 1935 requiring that all fires spotted on any day had to be controlled by 10 am the following day (National Forest Foundation, 2022).”

Comment: This statement advances the simplistic assertion that “Science has confirmed the overall benefit and necessity of forest fires”, while (1) ignoring the fact that fires today are more destructive than before—partially due to climate change—and (2) dismissing the very real impacts of modern fires on the American people.

The statement that “the highest profile U.S. forest fire remains the 1910 Big Blowup fire in the U.S. west” is highly subjective and unsupported. For example, over the past century in California alone, 18/20 of the most destructive fires (in terms of property lost), and 13/20 of the deadliest fires, have occurred since 2000 (CAL FIRE 2025a,b). Research has demonstrated that while part of this increase in destructive fires is due to more people living in the wildland-urban interface (WUI), coupled with a century of wildfire suppression leading to fuel build-up, climate change explains part of this increase in destructiveness. Specifically, climate change has led to elevated fire weather (Abatzoglou et al. 2025; Zhuang et al. 2021; [Goss et al. 2020](#); [Jones et al. 2022](#); Abatzoglou et al. 2019) and drier fuel ([Ellis et al. 2021](#); [Goodwin et al. 2021](#); Abatzoglou and Williams 2016; [Alizadeh et al. 2021](#)). Therefore, when fires ignite, they burn at higher intensity ([Parks and Abatzoglou 2020](#)). When drought-ridden forests experience these higher severity fires, this negatively impacts ecosystem recovery ([Turner et al. 2019](#); [Stevens-Rumann et al. 2018](#)). Furthermore, regarding the 10 am rule, climate change has made it more difficult to control fires overnight, when most fire suppression efforts have historically happened (Balch et al. 2022).

The broad generalization (“Forest fires have always been a part of nature”) neglects the human health and mortality, economic, and ecological tolls of high intensity and more frequent modern fires in some regions, such as the western US (Ostoja et al. 2023). First, recent fires (e.g., Lahaina, Maui; LA Eaton and Palisades fires; Paradise Fire) have led to hundreds of direct deaths. Furthermore, smoke exposure has increased morbidity and mortality among exposed populations (Law et al. 2025; Xu et al. 2020; Cascio 2018) and can lead to adverse pregnancy outcomes due to maternal exposure (Abdo et al. 2019). Wildfire smoke has “substantially slowed or reversed improvements in ambient PM 2.5 concentrations throughout much of the USA” (Burke et al. 2023). Smoke exposure also affects the eastern US, with high smoke-related mortality (O’dell et al. 2021) due to transported smoke from wildfires in Canada and the western US (Burke et al. 2021).

The economic cost (in terms of response and losses) of wildfires is tremendous and has been increasing over the last several decades (Bayham et al. 2022), with estimated federal response costs to fires in 2020 at ~\$2 billion, damages from 2020 fires at ~\$16.5 billion, and direct and indirect costs of 2018 fires in California at ~\$148.5 billion (Bayham et al. 2022; Wang et al. 2021). Rising insurance costs from wildfires have also led to market withdrawals in high-risk states like California, leaving homeowners uninsured and financially vulnerable (Almuhana,

2024, Auer, 2024). Wildfires also destroy forest stands used for timber (Bousfield et al. 2025) and contaminate drinking water supply (Murphy et al. 2018; Paul et al. 2022).

Finally, modern wildfires also threaten the capacity of forests to act as critical carbon sinks while releasing carbon dioxide, contributing to the acceleration of climate change in a positive feedback (Jones et al. 2024; Zheng et al. 2021; Liu et al. 2014).

Action: Therefore, the DOE CWG Report authors should revise this statement to specify that while certain types of fires are beneficial (especially prescribed burns), recent fires (of the past decades) have been highly destructive, in part due to climate change. The DOE CWG Report authors should incorporate the points we make (above), including the literature we reference.

Comment 8

Page 70 Section 6.8 Paragraph 3

Comment Type: Technical Comment

Statement: “While defeating all fires seemed a noble goal, questions began to arise as to whether this behavior “followed the science” (U.S. Forest Service, 2022). Over time the U.S. Forest Service has begun to rethink its goals, recognizing that new approaches such as prescribed burns, fuel elimination, and controlled wildfires are more appropriate (Sommer, 2016). Recent research is validating this approach and recognizing that more frequent smaller fires likely result in healthier forests, water ecosystems and biodiversity (Stephens et al., 2021).”

Comment: While low- and moderate-severity fire can be ecologically beneficial and help to reduce fuels, large, high-severity fires often have extremely negative impacts (see comment 7). However, due to climate change, there is a narrower window for when prescribed burns (i.e. ‘beneficial fire’) can be safely conducted ([Swain et al. 2023](#)).

Action: The DOE CWG report authors should more clearly differentiate between beneficial, lower-severity fire and high-severity fire (not just smaller or larger fires), and note the challenges that historical fire suppression and climate change pose to conducting prescribed burns.

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Technical Comment on the DOE CWG report, Chapter 7: Changes in Sea Level

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The opinions, findings, and conclusions or recommendations expressed are those of the authors.

This section is a **technical** comment on chapter 7 of the DOE CWG report (pp. 75-81).

Chapter 7 of the DOE CWG report addresses the topic of changes in sea level. As the chapter correctly notes, global-mean sea level (GMSL) has risen by about 8 inches since 1900, and this rise is “unambiguously associated with increasing temperatures” (p. 75). The chapter omits three critical assessments, discussed below:

- It conducts no systematic, statistical analysis to support its claim that there is “no obvious acceleration” of sea-level rise, either at individual tide gauges in the United States or in aggregate across U.S. tide gauges.
- It conducts no analysis to support its claim that sea level is rising at a lower rate than projected by the Intergovernmental Panel on Climate Change (IPCC)’s Sixth Assessment Report (AR6).
- It contains no discussion of the current or future impacts of sea-level rise on the United States.

It also contains numerous statements that are not supported by a balanced assessment of the scientific literature, utilizes cherry picked data, and has pervasive issues with inadequate citation practices. Specific examples are discussed below (pp. 75-81).

To correct for these issues, the following changes must be made in the DOE CWG document:

- Update the text to correctly cite literature showing an acceleration of sea-level rise beyond the historical average rate, as measured by geological proxy records, tide gauges and satellite altimetry, and correctly describe this acceleration in the report executive summary.

- Include an explanation of which tide gauges are highlighted in the report and why, as well as a summary of the aggregate trends as reported in Sweet et al., 2022 and other sources
- Update the text to reflect the consistency between sea-level observations and the IPCC AR6 projections.
- Include a discussion of the numerous current and future impacts of sea-level rise on the United States, including the costs of private and public adaptation to sea-level rise.
- Clarify that the role of vertical land motion as a key driver of spatial variability in relative sea-level change has been long understood, and that subsidence exacerbates the risks associated with climate-driven sea-level rise.
- Correct the additional errors and misrepresentations identified below.

Critical failings

This is a **technical** comment on the summary of chapter 7 (p. 75) and its representation in the report executive summary (p. ix), as well as the text of the chapter that supports (or fails to support) these summaries (pp. 75-81).

A vibes-based assessment of sea-level acceleration

¶1 of the chapter summary (p. 75) states that “U.S. tide gauge measurements reveal no obvious acceleration beyond the historical average rate of sea level rise”. **The report executive summary (p. ix)** embellishes the chapter summary statement, further claiming that “U.S. tide gauge measurements *in aggregate* show no obvious acceleration in sea-level rise beyond the historical average rate [Chapter 7]” (emphasis added).

Despite making this claim, the report contains *no analysis* of “U.S. tide gauge measurements in aggregate.” Whether or not acceleration is “obvious” to the authors of the DOE CWG report, Sweet et al. (2022) do analyze aggregate tide gauge measurements in the contiguous US (CONUS) and in regions of the United States and outlying islands. Their analysis, and follow-on Interagency analysis presented on the National Sea Level Explorer (earth.gov/sealevel/us), confirms sea-level acceleration since the 1970s in CONUS in aggregate, driven particularly by acceleration along the US Atlantic and Gulf Coasts (Figure 1). (The National Sea Level Explorer is a collaborative, interagency effort led by NASA, NOAA, and USGS.) Based on Interagency analysis, the CONUS aggregate rate of relative sea-level (RSL) rise has increased from 0.3 inches/decade (0.7 mm/yr) in the 1970s to 1.9 inches/decade (4.7 mm/yr) in the 2010s. Using a different statistical method, Piecuch (2025) demonstrates a sustained acceleration in CONUS sea level since 1900.

Contiguous United States

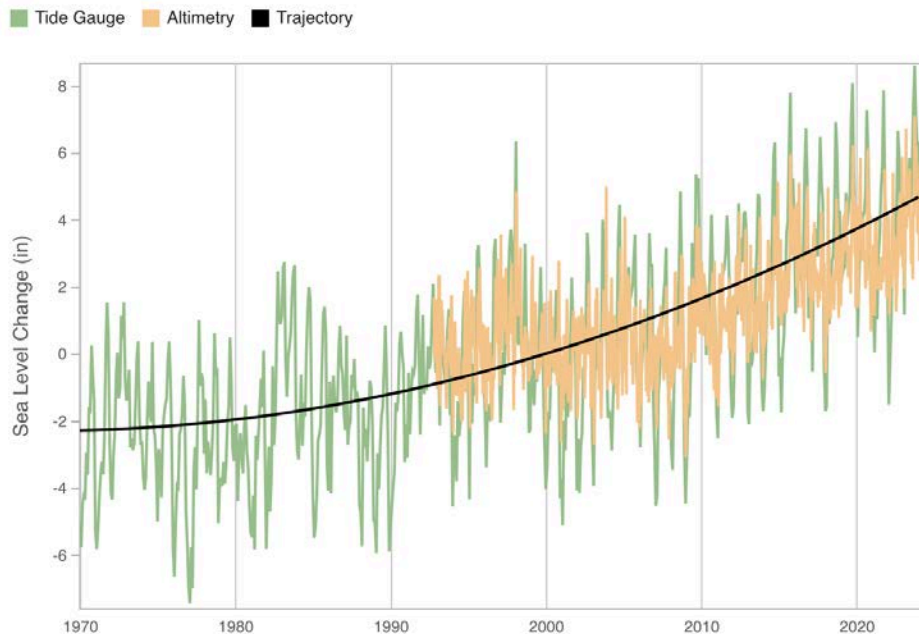


Figure 1. The aggregate tide-gauge and satellite altimetry record for the Contiguous US, showing clear acceleration from 0.3 inches/decade (0.7 mm/yr) in the 1970s to 1.9 inches/decade (4.7 mm/yr) in the 2010s. Source: https://earth.gov/sealevel/us/national-sea-level-explorer/?type=regional&region=USA&scope=section_1

The standard scientific approach for evaluating the presence of acceleration is through statistical analysis. The DOE CWG report, however, performs no statistical analysis to test for acceleration. Instead, it selectively shows graphs of linear fits to four selected tide U.S. tide gauges, and presents tabular results for these four gauges plus a fifth, uncharted tide gauge. It provides no rationale for how these five records were selected for presentation from among the 141 actively updated, long-duration NOAA tide gauges (<https://tidesandcurrents.noaa.gov/sltrends/mslUSTrendsTable.html>).

By contrast with the DOE CWG report's untested assumption of linearity, Interagency analysis shows that four of the five tide gauges the report focuses upon do indeed show an increase in the decadal rate of sea-level rise (i.e., an acceleration) of at least 1.5 inches/decade (3.8 mm/yr) between the 1970s and the 2010s (Figures 2-6). Note that the data for tide gauges and altimetry show a good correspondence (Figures 2-6) and changes in vertical land motion are taken into account (see below). The claims in the DOE report that there is no "obvious acceleration beyond the historical average rate of sea level rise" (p. ix and p. 75) are supported by the available empirical data and standard statistical analysis. **NOT**

The Battery (New York City)

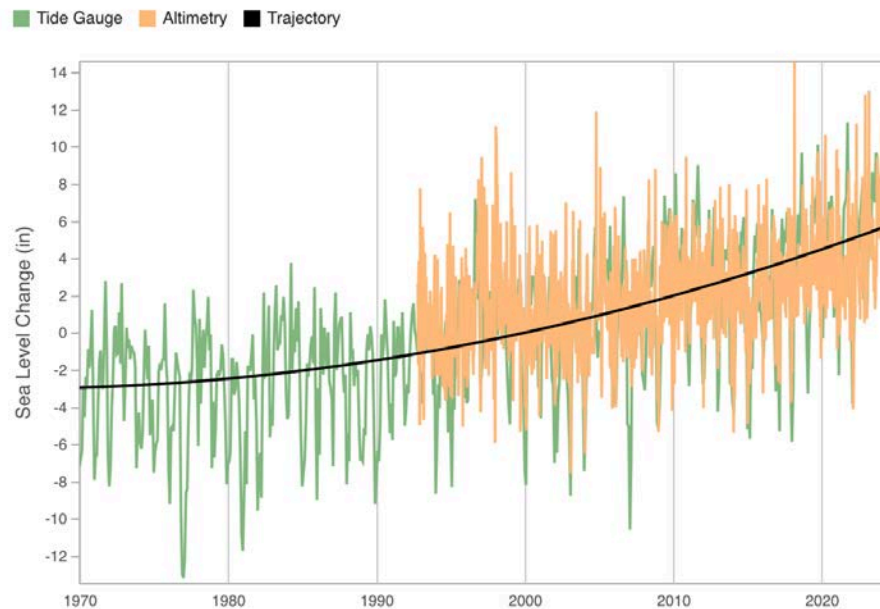


Figure 2. The tide-gauge and satellite altimetry record at The Battery (New York City), NY, showing acceleration from 0.5 inches/decade (1.2 mm/yr) in the 1970s to 2.5 inches/decade (6.3 mm/yr) in the 2010s. Source: https://earth.gov/sealevel/us/national-sea-level-explorer/?psmsl_id=12&scope=section_1

Galveston

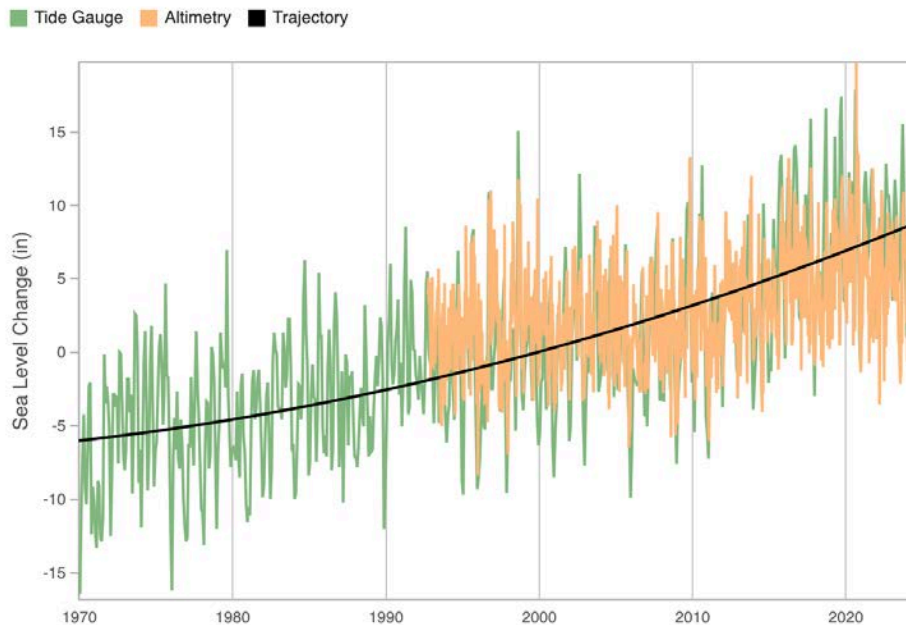


Figure 3. The tide-gauge and satellite altimetry record at Galveston, TX, showing acceleration from 1.4 inches/decade (3.6 mm/yr) in the 1970s to 3.7 inches/decade (9.4 mm/yr) in the 2010s. Source: https://earth.gov/sealevel/us/national-sea-level-explorer/?psmsl_id=161&scope=section_1

Grand Isle

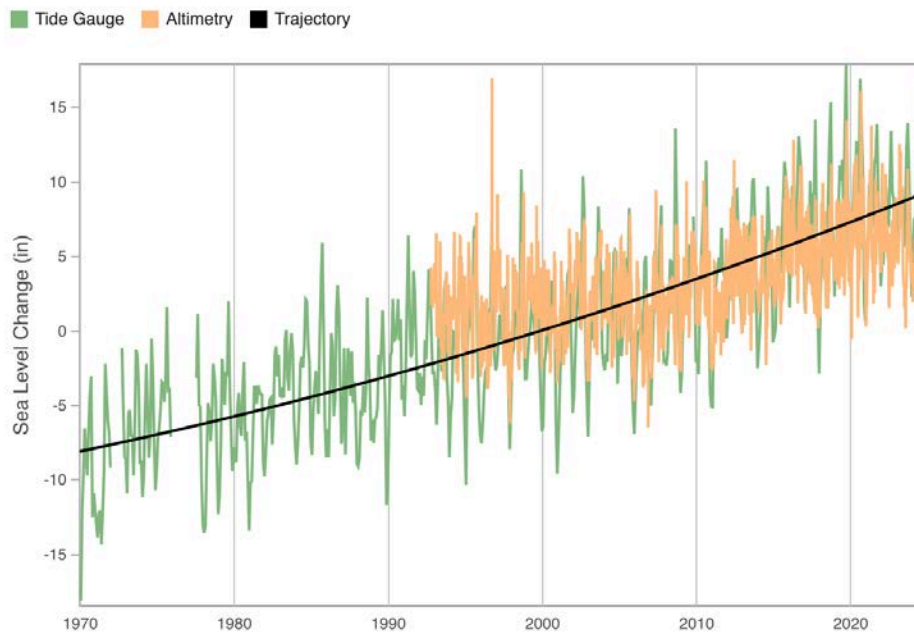


Figure 4. The tide-gauge and satellite altimetry record at Grand Isle, LA showing acceleration from 2.3 inches/decade (5.9 mm/yr) in the 1970s to 3.8 inches/decade (9.6 mm/yr) in the 2010s. Source: https://earth.gov/sealevel/us/national-sea-level-explorer/?psmsl_id=526&scope=section_1

St. Petersburg

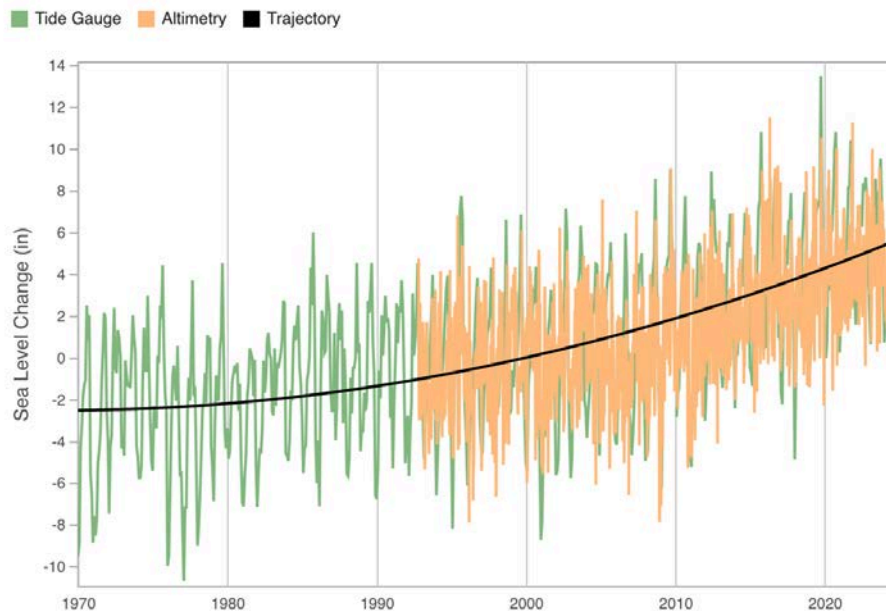


Figure 5. The tide-gauge and satellite altimetry record at St. Petersburg, FL, showing acceleration from 0.3 inches/decade (0.8 mm/yr) in the 1970s to 2.4 inches/decade (6.0 mm/yr) in the 2010s. Source: https://earth.gov/sealevel/us/national-sea-level-explorer/?psmsl_id=520&scope=section_1

San Francisco

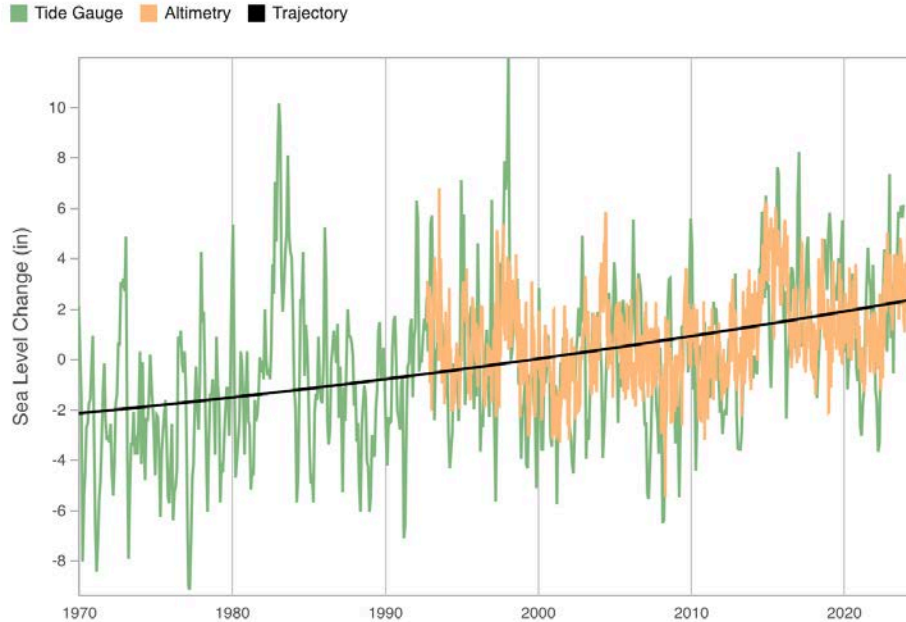


Figure 6. The tide-gauge and satellite altimetry record at San Francisco, CA, showing acceleration from 0.6 inches/decade (1.6 mm/yr) in the 1970s to 1.0 inches/decade (2.5 mm/yr) in the 2010s. Source: https://earth.gov/sealevel/us/national-sea-level-explorer/?psmsl_id=10&scope=section_1

The chapter also fails to acknowledge the substantial scientific literature documenting sea-level acceleration both in the global mean (Cazenave & Moreira, 2022; Dangendorf et al., 2024; Fox-Kemper et al., 2021; Hamlington et al., 2024) (Figure 7) and at a regional scale (e.g., Dangendorf et al., 2023; Ezer, 2023; Kopp, 2013; Walker et al., 2021). As the chapter rightly points out, sea-level rise monitoring over recent decades has been exceptional, providing a valuable understanding that informs future expectations (p. 75). Global-scale monitoring of sea-level rise was first enabled by satellite altimetry, which launched in late 1992 and achieved unprecedented precision in monitoring GMSL change (order of 1 mm yr^{-1}). This precision made possible the detection of a GMSL acceleration of $0.084 \pm 0.025 \text{ mm yr}^{-2}$ from 1993 to 2018 directly from satellite data (Nerem et al., 2018), the emergence of which was predicted using climate model large ensembles several years earlier (Fasullo et al., 2016). The evident global acceleration of sea-level rise (Figure 7) is not discussed in the report.

The DOE CWG report mentions “current” rates near 0.12 inches/yr (3.0 mm/yr), presumably referring to the 1993-2020 averages (p. 75). In truth, however, GMSL rise has accelerated during that period, and it is now estimated that the GMSL rate has doubled during the three decades of satellite altimetry, increasing from about 0.08 inches/yr (2.1 mm/yr) in 1992 to about 0.18 inches/yr (4.5 mm/yr) in 2024 (Hamlington et al., 2024). The rate of GMSL rise is expected to continue increasing as long as global mean surface temperature continues to increase (Grinsted et al., 2022; e.g., Grinsted & Christensen, 2021; Hermans et al., 2021).

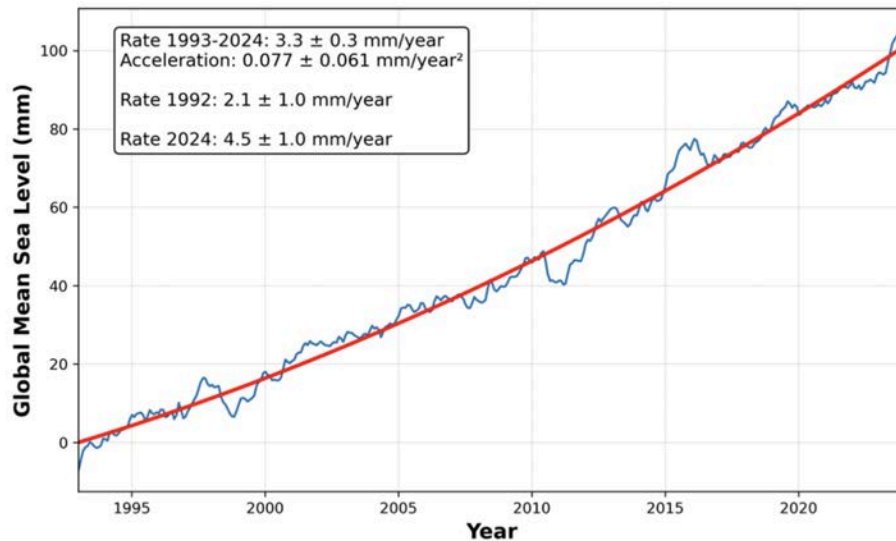


Figure 7. Global mean sea level time series (mm) from satellite altimetry over the time period from 1993 through 2023. The solid red line is the quadratic fit to the data and indicates the sea-level change over the altimeter record relative to 1993. Reproduced from Hamlington et al. (2024).

A missing evaluation of Intergovernmental Panel on Climate Change sea-level projections

¶2 of the chapter summary (p.75) states that “Extreme projections of global sea level rise are associated with an implausible extreme emissions scenario and inclusion of poorly understood processes associated with hypothetical ice sheet instabilities. In evaluating [IPCC] AR6 projections to 2050 (with reference to the baseline period 1995-2014), almost half of the interval has elapsed by 2025, with sea level rising at a lower rate than predicted” (p. 75).

However, the chapter text does not evaluate Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) projections, making it impossible to understand the grounds upon which the authors claim that “sea level [is] rising at a lower rate than predicted.” Had the authors conducted such an evaluation, the evaluation would have shown that current rates of sea-level rise are consistent with AR6 projections. Relative to 1995-2014, AR6 estimates a 19-year average global mean sea level centered in 2020 of 4-6 cm (4-7 cm when allowing for rapid ice sheet loss processes). While we do not have the full data set for 2011-2029 to enable calculation of the observed value, extrapolating observations, as in Sweet et al. (2022) or Hamlington et al. (2024), yields a value for 2020 of about 5-6 cm, fully consistent with the AR6 projections.

Similarly, Hamlington et al. (2024) extrapolated the observed GMSL acceleration to 2050, projecting 21 ± 5 cm of GMSL rise between 2008 and 2050. This range is consistent with AR6 projections under all emissions scenarios (Figure 8). Wang et al. (2025) show that observation-based extrapolations of tide-gauge data and AR6 medium-confidence projections agree within the *likely* range for 2050 at 96% of the 222 tide gauges they examine, including The Battery (New York City) tide gauge that the DOE CWG highlights in section 7.3.

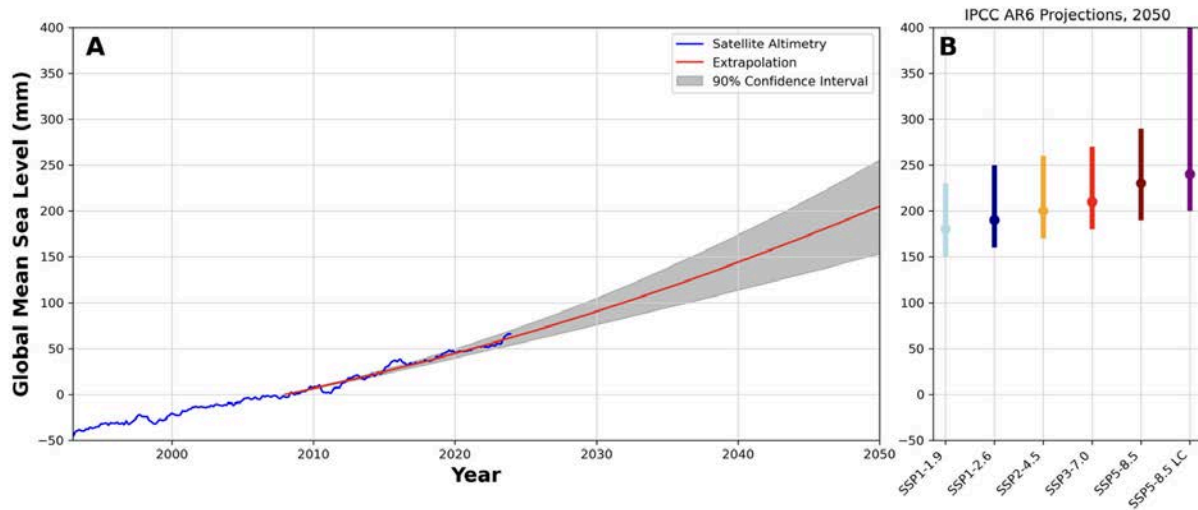


Figure 8. A Extrapolation of the quadratic fit to the satellite altimeter record to 2050. The gray shaded area reflects the 90% confidence interval on the extrapolated sea level. **B** the model-based projections from the IPCC AR6 for six of the different scenarios considered. Error bars on the projections indicate the *likely* range for each scenario. The SSP5-8.5 LC scenario indicates the Low Confidence scenario used in the IPCC AR6. Reproduced from Hamlington et al. (2024).

The chapter text also does not assess the extensive and rapidly evolving literature on ice sheet dynamics, mass balance and instabilities (e.g. Millan et al, 2023; Davis et al, 2023; Ryan et al, 2023). Moreover, ice sheet model projections underestimate consensus estimates of ice sheet mass change (e.g., Aschwanden et al., 2021), which reaffirms the potential for sea-level contributions towards the higher end of the AR6 projection range (see also, e.g., Badgeley et al., 2025; Box et al., 2022).

Although the chapter claims to provide an evaluation of sea-level rise projections, Chapter 7 of the DOE CWG also fails to discuss nearly all of the peer-reviewed projection studies of global sea-level rise that have been published in recent years. Between 2013 and 2018 alone, 30 unique, peer-reviewed studies published global sea-level rise projections (Garner et al., 2018). Since 2018, there have been more than a dozen additional peer-reviewed publications producing global sea-level rise projections. Despite the multitude of sea-level rise projections published in the scientific literature, the authors of the DOE CWG discuss only the Sweet et al., 2022, Interagency sea-level scenarios (Sweet et al., 2022), with a cursory mention of the IPCC AR6 projections, from which the Interagency scenarios are derived (Fox-Kemper et al., 2021).

A missing review of impacts of sea-level rise on the United States

Notably absent from chapter 7 (pp. 75-81) of this “critical reviews of impacts” is any review of the impacts of sea-level rise on the United States, either at present or in the future. The closest the chapter gets to addressing this topic is a brief (uncited) dismissal stating that “concern over sea level rise is not about the roughly eight inches of global rise since 1900” (p. 79). In fact, by making coastal flooding more frequent, the effects of historic sea-level rise are already causing measurable economic harm to the United States (e.g., Buchanan et al., 2017; Garner et al.,

2017; Sweet et al., 2024). Other current impacts of historic sea-level rise include more frequent saltwater intrusion into groundwater, more frequent groundwater flooding, and coastal erosion, including loss of tidal wetlands as rates of RSL rise start to exceed the rates at which accretion can keep pace (May et al., 2023; Saintilan et al., 2023).

Annapolis

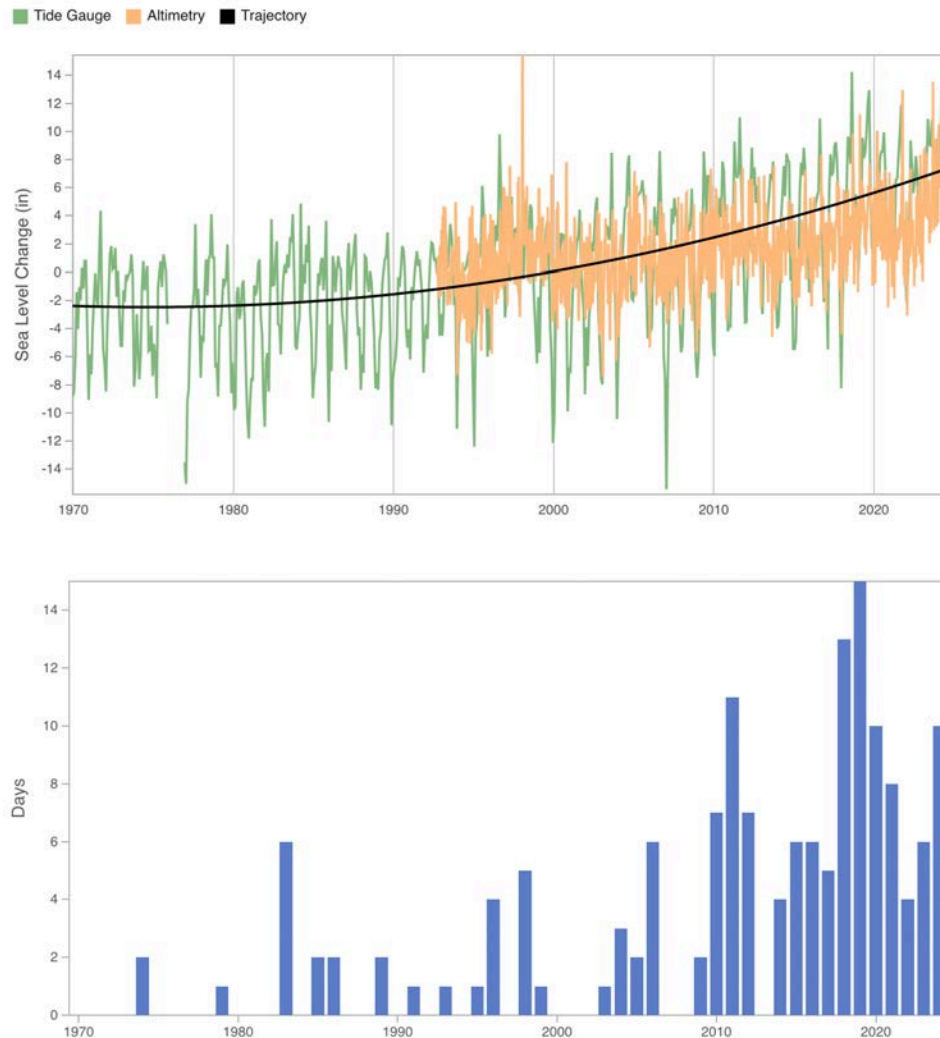


Figure 9. (top) The tide-gauge and satellite altimetry record at Annapolis, MD, showing acceleration from 0.0 inches/decade in the 1970s to 3.1 inches/decade in the 2010s. Source: https://earth.gov/sealevel/us/national-sea-level-explorer/?psmsl_id=360&scope=section_1 (bottom) The number of days per year at Annapolis, MD, at which water levels exceeded the NOAA minor flooding threshold. These have grown from 0.3 days/yr on average in the 1970s to 8.3 days/yr on average over 2015–2025, as a result of relative sea-level rise. Source: https://earth.gov/sealevel/us/national-sea-level-explorer/?psmsl_id=311&scope=section_2

Section 7.2, ¶1 (p. 75) makes specific reference to the Chesapeake Bay region, which includes the Nation’s capital of Washington, DC, as one area of the U.S. coasts in which sea level increases are associated with local land sinking unrelated to climate change. While the rate of subsidence has remained fairly constant, RSL rise accelerated over 1975 to 2021 at all of the

Bay's tide gauges (Ezer, 2023). While subsidence was just under half of the relative sea-level rise during the mid-20th century, it is now less than 30%.

This RSL rise has driven an escalating frequency of coastal flooding, with measurable economic costs. In 2017, high-tide flooding reduced visits to Annapolis's historic downtown by an estimated 1.7% (95% confidence interval, 1.0-2.6%) (Hino et al., 2019). Annapolis experienced 5 high-tide flooding days in 2017, and an average of 8 per year over the last decade (Figure 9). Even under Sweet et al. (2022)'s Low scenario – which involves a reversal of the current global-mean sea-level rise acceleration, such that the 21st century rate of rise averages 0.12 inches/year (3.0 mm/yr) – Annapolis is expected to experience an average of 75 high tide flood days/year in 2050, compared to 8 per year over the last decade (https://earth.gov/sealevel/us/national-sea-level-explorer/?psmsl_id=311&scope=section_2).

Similar historic increases in coastal flooding are seen elsewhere in the country, and expected relative sea-level rise is projected to increase high-tide flooding by 5-10x on average across the country by 2050 in most locations (May et al., 2023; Sweet et al., 2022).

Tidal flooding delayed commuters in US coastal counties by an average of 23 minutes/year in 2017, compared to about 12 minutes/year in 2002, and that this average delay would increase to 183 minutes/year in 2060 under the Interagency Low scenario (Hauer et al., 2023).

The effects of sea-level rise are also manifest in more extensive, expensive, and frequent storm-driven flooding. For example, about 13% of Hurricane Sandy's damage (about \$8 billion) and 9% of its population flood exposure (about 70,000 people) in the New York/New Jersey/Connecticut tri-state area would not have happened without human-caused sea-level rise (Strauss et al., 2021).

Projected sea-level rise will have profound effects on many coastal communities. In the absence of protective measures, sea-level rise under a moderate emissions SSP2-4.5 scenario is projected to displace about 1.5 million Americans by the end of the century, with consequent demographic feedbacks effects leading to a shift in population away from coastal counties of about 15 million people (Hauer et al., 2024). These demographic shifts will significantly affect the economic future of coastal communities, including stresses on local government finances (Gilmore et al., 2022). Increasing coastal flood hazards also risk destabilizing insurance markets (Kousky et al., 2024). In remote regions such as northern Alaska, coastal communities face additional adaptation challenges, in part due to settlement patterns in Indigenous communities which were shaped by colonization (Buzard et al., 2024).

Chapter 7 excludes any analysis of adaptation with respect to sea-level rise. Adaptation can reduce, but not eliminate, damages associated with future sea-level rise. For example, damages to U.S. coastal properties due to anticipated sea-level rise are expected to reach \$10–37 billion/year by 2090 in the absence of adaptation, but would still be \$7–8 billion/year even with cost-benefit optimal adaptation (Hartin et al., 2023). Yet the United States is not optimally adapted even to current coastal hazards (e.g., Lorie et al., 2020). Economically efficient adaptation will require substantial investments by individuals, industries, and local-to-federal

governments well in advance, and failure to make such investments will decrease economic stability (e.g., Kousky et al., 2024). Furthermore, adaptation planning that neglects diverse communities and histories within the United States, including racialized communities and coastal Tribal Nations, risks exacerbating inequities (Hardy et al., 2017; Leonard, 2021).

In addition, many low-lying regions will reach adaptation limits over the course of this century (Magnan et al., 2022). Expensive wholesale relocation will be required in some areas, which comes with major non-financial costs in terms of employment and family and social cohesion. Planned and managed relocation in response to increased flooding threats affected by sea-level rise has not yet been successful at scale.

Additional comments on 7.1. Global sea level rise (p. 75)

This section is a **technical** comment on section 7.1 of the DOE CWG report (p. 75). It supplements comments made above with respect to treatment of sea-level acceleration in this chapter.

Section 7.1 is an approximately accurate summary of the importance of global-mean sea-level rise, its main drivers, and its historic rates (p. 75).

¶1 (p.75) correctly notes that GMSL rise is driven primarily through thermal expansion, glacier and ice sheet mass loss, and changes in land-water storage—a fact that has been well understood in the scientific community for over four decades (e.g., Gornitz et al., 1982; Hoffman et al., 1983; Revelle, 1983). It also notes that regional sea-level change differs from GMSL change due to changes in (atmosphere/ocean circulation, vertical land motion, and “geological processes and deformation from the redistribution of ice and water”—again a fact that the scientific community has long understood (e.g., Clark & Lingle, 1977; Gutenberg, 1941). If by “geological processes” the authors intend to refer to the geophysical processes of Earth gravitation and rotation, this statement is conceptually correct though incorrectly articulated. These geophysical processes, together with associated lithospheric and mantle deformation, are referred to as “gravitational, rotational and deformational” (GRD) effects by sea-level scientists (Gregory et al., 2019).

¶2 (p.75) summarizes the AR6 assessment of historic sea-level change. AR6 assesses the very likely range of 1901-2018 GMSL rise to be 150.3-253.5 mm (5.9-10.0 inches), with a median estimate of 201.9 mm (7.9 inches) (Fox-Kemper et al., 2021).¹ Chapter 7’s quoted rate of GMSL rise is 0.12 inches/year (3.0 mm/yr), which is slightly lower than the AR6 assessment that the rate of GMSL rise over 1993-2018 was 3.25 (2.88-3.61) mm/yr [0.13 (0.11-0.14) inches/year].

The reference that DOE CWG cites for the rate of GMSL rise does not exist. The text cites NASA. (2020). *NASA sea level rise portal: 2020 edition*. <https://www.nasa.gov/specials/sea-level-rise-2020/>. The NASA Sea Level Change Portal (sealevel.nasa.gov) never had that title, and the link provided is not to any version of the portal, but rather to a video “Rising Waters,” which provides “A look at how NASA is dealing with the

¹ The report incorrectly converts 253.5 mm to 9.8 inches.

threat of sea level rise to its coastal infrastructure, particularly at Langley Research Center in Hampton, Virginia, and Ames Research Center in Mountain View, California.”

¶3 (p. 75) states that “Following the end of the Little Ice Age in the mid-nineteenth century, tide gauges show that the global mean sea level began rising during the period 1820-1860, well before most anthropogenic greenhouse gas emissions.” It is not possible to evaluate GMSL before the late nineteenth century based on tide gauge data alone, due to the sparsity of records, and the authors provide no citation to support this statement.

Adequately reconstructing GMSL before the 20th century requires the inclusion of geologic proxy data because tide-gauge data are too sparse. For example, by combining tide-gauge and geological data, Walker et al. (Walker et al., 2022) show that “it is very likely that rates of sea-level rise emerged above pre-industrial rates by 1863 CE ($P=0.9$; range of 1825 [$P=0.66$] to 1873 CE [$P=0.95$]), which is similar in timing to evidence for early ocean warming and glacier melt.” The partitioning of the drivers of this emergence between natural factors and anthropogenic factors remains unclear. Notably, Santer et al. (Santer et al., 2025) show that an anthropogenic signal in the atmosphere would have been detectable by the 1880s (~290 ppm CO₂) (possibly earlier, since their analysis starts in 1850, by which time CO₂ concentration had already risen to 285 ppm, above an eighteenth century level of about 277 ppm).

Additional comments on 7.2. U.S. sea level rise (p. 75-79)

This section is a **technical** comment on section 7.2 of the DOE CWG report (p. 75-79). It supplements comments made above with respect to treatment of sea-level acceleration in this chapter.

The purpose of section 7.2 is unclear (p. 75-79). Largely, this section is a tour of 4-5 seemingly arbitrarily selected U.S. tide gauge records, primarily making the point that vertical land motion (of both natural and anthropogenic origin) is an important contributor to relative sea-level rise, and its spatial variability. This statement is true and uncontroversial, as reflected in the NOAA map reproduced as Figure 7.1.

In considering the role of vertical land motion (VLM) in tide-gauge records, it is important to note that subsidence exacerbates the risks of climate-driven sea-level rise. Indeed, if GMSL rise ends up on the lower side of projections, communities with larger subsidence will be more disproportionately at risk. Local subsidence is a risk amplifier, not a reason to ignore the need for adaptation to climate-driven sea-level rise.

By failing to evaluate US tide gauge records in the context of GMSL acceleration, Section 7.2 (p. 75-79) presents an incomplete and skewed perspective.

The presentation in section 7.2 (p. 75-79) stresses the importance of VLM in contrast to rising sea-surface height (what the authors term “absolute sea level rise,” or which the modern sea-level research community calls ‘geocentric sea-level rise’ (Gregory et al., 2019)). It does not consider that the latter is increasingly adding to the threats due to the former. The relative sea-level rise rates provided in Table 7.1 are presumptively century-scale trends, and do not

reflect the acceleration that has been observed in satellite and tide gauge records over the past few decades at many locations (e.g., Dangendorf et al., 2023).

¶2 (p. 76) states that “measurements of relative sea level rise from tide gauges conflate the climatologically relevant increase in the volume of seawater with local vertical land motion.” Definitionally, RSL rise is “the change in local mean sea level relative to the local solid surface, i.e., the sea floor” (e.g., Gregory et al., 2019). There are thus two errors in the report statement.

First, measurement of RSL change is not a ‘conflation’ of a climatic signal; it is a measurement of the climate-impact driver most closely related to the local increasing coastal flood hazard. To say that RSL measurements ‘conflate’ the increase in seawater volume with vertical land motion suggests a misunderstanding of relative sea-level rise and its importance as a climate-impact driver. Second, the authors’ statement seems to imply the only climatologically relevant contributor to RSL change is the change in the global volume of seawater. This implication neglects the role of atmosphere/ocean dynamics, as well as the role of the gravitational and rotational effects of redistributing ice and water mass. Like vertical land motion, these factors “var[y] from place to place.”

¶3 and following (p. 76-79), including Figures 7.2-7.5 and Table 7.1. The authors’ Table 7.1, and associated text in section 7.2, is of unclear provenance and significance. No sources are provided for the tide gauges or VLM data. No confidence intervals are quoted in this table, nor are the methods used to calculate the rates anywhere documented. Though the records discussed are all of different lengths, the time period(s) over which rates are quoted are not specified.

We expect the time period over which VLM is estimated is different than the time period over which RSL rise is estimated (since GPS data, the likely source, has been available only in recent decades); whether VLM rates can be assumed constant and therefore can appropriately be extrapolated for the length of the tide gauge record will differ depending on the driver. Constant rates are a fine assumption if glacial-isostatic adjustment is the dominant driver, as in New York, but not if anthropogenic factors dominate, as in Galveston and Grand Isle (Kearns et al., 2015; Kolker et al., 2011).

Additional comments on 7.3. Projected sea level rise (p. 79-80)

This section is a **technical** comment on section 7.3 of the DOE CWG report (p. 79-80). It supplements the comments above on evaluation of sea-level projections and on the impacts of sea-level rise.

Section 7.3 (p. 79-80) is largely a summary of the IPCC AR6 assessment of projected sea-level rise, with the final paragraph critiquing the US Interagency sea-level rise scenarios, as misinterpreted by the authors.

¶2-¶3 (p. 79-80). These paragraphs attempt to summarize IPCC AR6 sea-level rise projections. (The projections, both globally and locally, are readily available on the web at <https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool>.)

The numbers quoted for AR6 by the DOE CWG are difficult to trace, because the authors do not appear to understand the role of assessment language in the IPCC. A “likely” or “very likely” assessment is not simply a mechanical reporting of a computed probability distribution, but an expert assessment that there is at least a 66% (likely) or 90% (very likely) chance the correct value falls within the quoted range. AR6 deliberately *did not* assess *very likely* ranges for projected sea-level rise, given the potential contributions from deeply uncertain processes; instead it assessed the *likely* contributions (only) from those processes characterized by at least medium confidence. 5th–95th percentile ranges are computed and reported in the underlying data sets, but are *not* assessed ‘very likely’ ranges. Considering only processes with at least medium confidence, across all emissions scenarios, AR6 assessed a *likely* rise in 2050 between 15–29 cm (6–11 inches), relative to a 1995-2014 baseline. For 2100 in SSP2-4.5, the corresponding *likely range* is 44–76 cm (17–30 inches). See Kopp et al. (Kopp et al., 2023) for a discussion regarding the communication of uncertainty in IPCC sea level projections.

(Also note that at a few places in Chapter 7 of the DOE CWG, numbers reported to centimeter precision are reported to the nearest hundredth of an inch (i.e., nearest 0.03 cm), which vastly overstates the statistical confidence. This practice is inappropriate (Taylor, 1997) and characteristic of a general disregard for appropriate use of statistics throughout the chapter.)

¶4 (p. 80) and Figure 7.6 purport to compare rates of RSL rise at the Battery to the “NOAA” (US Interagency) sea-level rise scenarios (Sweet et al., 2022), arguing that, “[Sweet et al., 2022] claim that by 2050, the sea will have risen one foot at The Battery in Manhattan (relative to 2020)”. There are several problems with this comparison, which misconstrues the purpose of the Interagency planning scenarios, cherry picks a single scenario in a manner that neglects the range of estimates associated with it, and inaccurately reports scenario sea levels. (The following analysis uses the data sets available for download at <https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool> and <https://sealevel.nasa.gov/task-force-scenario-tool>).

The Interagency report provides a set of scenarios to support decision making, derived from the science in AR6. These scenarios are based on assumed amounts of sea-level rise by 2100, and they are intended to support different decision contexts by spanning a broad range of possible future outcomes. The Interagency scenarios are not independent of the AR6 projections, the evaluation of which we discussed above.

The Interagency report includes five scenarios. The “Low” scenario corresponds to a reversion of rates of GMSL rise to their early 21st century average, such that the average 21st century rate would be 3.0 mm/yr. The “Intermediate-Low” scenario is consistent with the AR6 median projection under a sub-2°C warming scenario (SSP1-2.6), and the “Intermediate” scenario is consistent with the upper end of likely range projections in the absence of deeply uncertain rapid ice sheet loss processes. The “Intermediate-High” and “High” scenarios require increasingly significant contributions from such ice sheet processes.

At the Battery, the Interagency scenarios reflect (Figure 10):

- Low: 21 cm of increase from 2020-2050 (range of 15-27 cm)
- Intermediate-Low: 24 cm of increase from 2020-2050 (range of 19-30 cm)
- Intermediate: 27 cm of increase from 2020-2050 (range of 22-34 cm)
- Intermediate-High: 33 cm of increase from 2020-2050 (range of 25-44 cm)
- High: 37 cm of increase from 2020-2050 (range of 27-50 cm)

It is thus unclear where the authors would have gotten a “one-foot [i.e., 30 cm] rise in thirty years.

Again, these are scenarios for planning; to assess likelihoods, we must turn to AR6. At the Battery, AR6 (medium confidence) assesses a *likely* RSL rise in 2050 (relative to 2005) of 24-50 cm, across emissions scenarios. Under SSP2-4.5, the median projection is for 26 cm of RSL rise between the 19-year period centered on 2020 and the 19-year period centered on 2050 (thus, an average rate of about 3.4 inches/decade). This is consistent with the Interagency report’s extrapolation of the observed acceleration since 1970 (Figure 10).

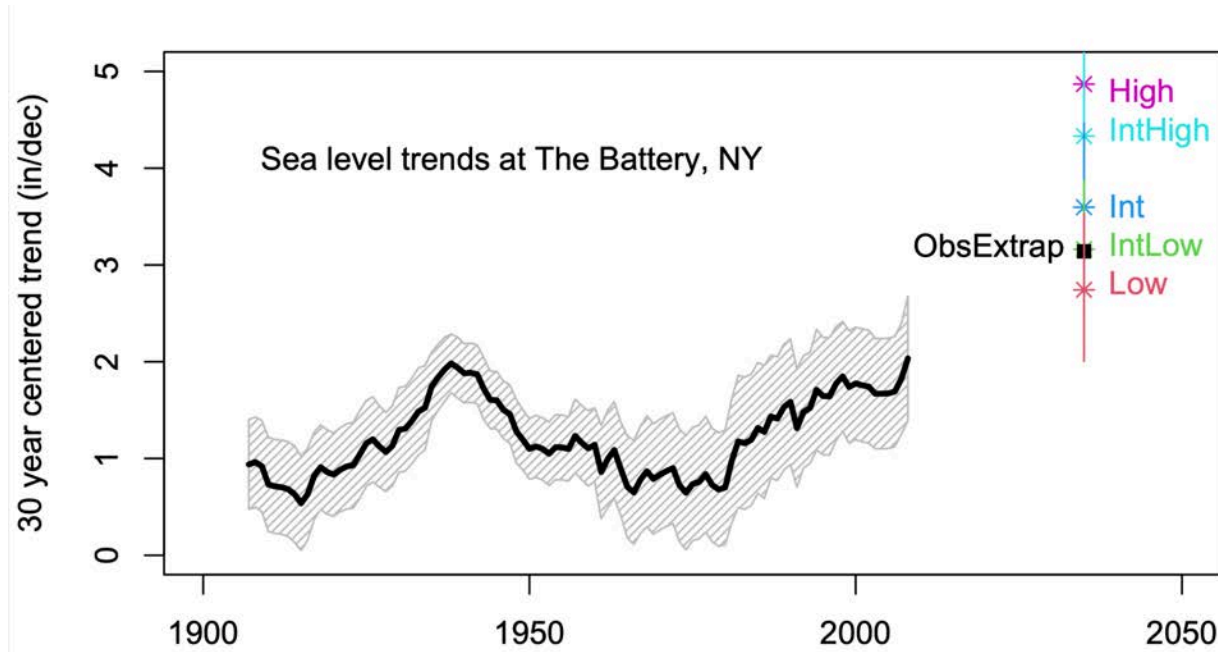


Figure 10. 30-year centered trends in the Battery tide gauge record, compared to the 2020-2050 average rates of increase in the 5 Interagency scenarios (Sweet et al., 2022) and the extrapolation of observations since 1970. (See Figure 2 for the trajectory underlying the extrapolation.)

¶4 (p. 80) and Figure 7.6 also reflect a more fundamental issue: the implicit message of this paragraph is that projections should be evaluated one tide gauge at a time. This comparison might make sense if tide gauges reflected independent time series, and there was no understanding of the physical processes that – individually and collectively – drove the changes observed at tide gauges. This situation is not, however, the case.

A comparison of tide gauge data to projections one tide gauge at a time is inherently flawed. Data-model comparisons must account for the totality of evidence — the global set of tide

gauge data, satellite observations of changes in sea surface height, observations of changes in ocean heat content and land ice mass, the scaling relationship between global-mean surface temperature and rate of sea-level rise, etc. More local and variable factors, such as atmosphere-ocean dynamics, can lead to misleading inferences if the global data set and context is excluded, as in the report's analysis.

The relatively high rate of sea-level rise at the Battery in the 1930s, for example, occurred in association with a relatively rapid increase in Northern Hemisphere extratropical temperature (about 0.2°C/decade warming from 1910-1940; compare 0.07°C/decade *cooling* from 1940-1980 and 0.4°C/decade warming from 1980-2020; 24°N-90°N averages from GISTEMP Team, 2025), an associated reduction in glacier ice mass, and an associated period of relatively high rates of GMSL rise (about 2 mm/yr in the late 1930s, vs. about 1 mm/yr in 1960s and more than 4 mm/yr today) (Dangendorf et al., 2024).

Comprehensive analyses are more challenging than simply plotting projections at one tide gauge against that tide gauge's data, but exist in literature not cited by the DOE CWG report. Dangendorf et al. (2024), for example, present a reconstruction of sea level over space and time that is informed by the global set of tide gauge data as well as a variety of constraints on land ice and water storage changes. They find clear evidence of a sustained acceleration in rates of GMSL change since the 1970, as well as in sea-level rise in the subtropical North Atlantic (which includes the US Atlantic and Gulf Coasts), the South Atlantic, and the East Pacific. As noted above, the observed acceleration is consistent with Interagency scenarios.

In considering projections of future sea-level rise, it is important to recognize that rates of sea-level rise are increasing because human activities are changing the climate. Given rising temperatures, it would be surprising and contrary to current understanding of the physical system for the rate of GMSL rise not to accelerate (Grinsted & Christensen, 2021). With global mean surface temperature continuing to rise, we should indeed expect future rates of global sea-level rise – which, in the twentieth century, were already the highest in at least 3000 years (Kemp et al., 2018; Kopp et al., 2016; Walker et al., 2021) – to be “remarkable” in “historical context” (p. 80).

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Comment on Section 8, Uncertainties in Climate Change Attribution

Nathan Gillett, CCCma, Environment and Climate Change Canada

Page: 84

Comment type: Technical

Comment: The paragraph on solar variability quotes an estimate of radiative forcing due to TSI changes over the period 1750-2011 from AR5 (0.05 W/m^2). It then quotes a change in TSI between the Maunder Minimum and the second half of the twentieth century of $0.7\text{-}2.7 \text{ W/m}^2$ from Gulev et al. (2021). But the associated radiative forcing change is much less than the TSI change (because it is an average over the surface area of the globe, and because some irradiance is reflected). Gulev et al. (2021) follow the quoted TSI change with the sentence “This TSI increase implies a change in ERF of $0.09\text{--}0.35 \text{ W m}^{-2}$ ”. The authors should quote this ERF change not the TSI change for comparability with the ERF change quoted earlier in the paragraph.

Page: 85

Comment type: Technical

Comment: Kravtsov et al. (2024) analysed the CMIP5 climate models. However, the more recent CMIP6 climate models as a group show more multi-decadal variability than the CMIP5 models. Eyring et al. (2021) assessed “Parsons et al. (2020) found that some CMIP6 models exhibit much higher multi-decadal variability in GSAT than CMIP5 models, with indications that variability in these models is also higher than that from proxy reconstructions”. The authors should cite and discuss Parsons et al. (2020) and the multi-decadal variability in CMIP6 models here.

Page: 85

Comment type: Technical

Comment: The authors write “However, the recommended forcing dataset for the CMIP6 climate model simulations used in AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017). While AR6 shows a substantially greater solar impact than does AR5, the overall impact of solar forcing on the climate was still assessed to be small compared to anthropogenic forcing. However, the impact of solar variations on the climate is uncertain and subject to substantial debate (Lockwood, 2012; Connolly *et al.*, 2021) - something that is not evident in the IPCC assessment reports.” In the executive summary, they write “Moreover, solar activity's contribution to the late 20th century warming might be underestimated [Section 8.3.1].”.

But, as the authors themselves explain, many attribution studies use regression to estimate the contribution of individual forcings to observed temperature changes. Two of the studies used to

estimate anthropogenic and natural contributions to observed temperature change by Eyring et al. (2021) in the latest IPCC report, constrain the amplitude of the naturally-induced temperature changes directly from observed temperature changes in a regression (Haustein et al., 2017; Gillett et al., 2021). If the simulated response to natural forcings were underestimated in the models, this would be corrected in the regression – the simulated response would have to be scaled up to fit observations. There is no evidence of this (Eyring et al., 2021). The authors should revise the text to reflect this.

Pg: 86

Comment type: Technical

Comment: The authors write “Once the simulations of the ensemble members and different models are averaged, the natural internal variability contribution is averaged out owing to differences in phasing, effectively cancelling the role of natural internal variability in the attribution process.” This is incorrect. While ensemble means are indeed used to estimate the forced response from climate model simulations in standard optimal fingerprinting, internal variability is estimated directly from observations, as a residual from the regression against simulated forced responses. This is compared with simulated variability using a residual test to examine whether or not the residual variability is consistent with simulated internal variability. See for example Allen and Tett (1999), or Ribes et al. (2013b) for discussion of the residual test. The authors should correct this error.

Pg 88:

Comment type: Technical

The authors write “While [optimal fingerprinting] has been widely used and prominently featured by the IPCC since 2001, there is very little literature examining the statistical properties of the results it generates.” This is not the case. There is extensive literature on the statistics of optimal fingerprinting. See for example the review in Eyring et al. (2021), Section 3.2.1. Or see Ribes et al. (2013a; 2013b). The authors should correct this error.

Pg 89:

Comment type: Technical

Comment: The authors write “Under conditions that easily arise in optimal fingerprinting, TLS estimates have a large positive bias. Thus, any study that used TLS for optimal fingerprinting without verifying its applicability in the specific data context has likely overstated the attribution.” IPCC (2021) based its assessment of human-induced climate change primarily on the results of three approaches: Haustein et al. (2017); Ribes et al. (2021) and Gillett et al. (2021), as described in Eyring et al. (2021). Of these three studies, the only one which used TLS regression was Gillett et al. (2021).

Gillett et al. (2021) did indeed verify the applicability of the TLS results by applying an imperfect model test to evaluate the approach – a historical simulation from one model was treated as pseudo-observations, and the TLS approach with simulations from the remaining models was used to estimate the response to aerosols, greenhouse gases and other anthropogenic forcings,

and natural forcings in the withheld model. This was then compared with that simulated directly by the model. No bias in the results was found – see Gillett et al. (2021), Figure 3. The authors should describe how Gillett et al. (2021) find no such large positive bias in a practical implementation of TLS.

Pg 89:

Comment type: Technical

Comment: The authors write “In summary, the primary statistical methods for attributing causation in climate data are optimal fingerprinting and time series analysis. Applications of the Allen and Tett (1999) optimal fingerprinting method dominate the attribution literature and have underpinned past IPCC conclusions, but results depend on the accuracy of climate models and the method has recently been criticized as inherently biased.” IPCC (2021) based its quantitative assessment of human-induced climate change on the results three approaches: Haustein et al. (2017); Ribes et al. (2021) and Gillett et al. (2021), as described in Eyring et al. (2021). Haustein et al. (2017) used a simple Ordinary Least Squares regression, and output from an energy balance model. Ribes et al. (2021), did not use a regression at all, but rather a kriging approach. Gillett et al. (2021) used a total least squares regression. All three studies gave similar results (see Eyring et al. (2021), Figure 3.8). Moreover, a bottom-up approach which did not use optimal fingerprinting or climate models at all (as described in IPCC AR6 WGI Chapter 7, and as also shown in Eyring et al. (2021), Figure 3.8) also gave similar results. Therefore the attribution results described in the most recent IPCC report are not based on a single approach – rather they are based on multiple consistent lines of evidence. The authors should revise this text to reflect this.

Pg 97:

Comment type: Technical

Comment: The authors write “peer-reviewed analyses showed that the event [the 2021 PNW heat wave] was caused by rare meteorological conditions that were not made more probable by global warming.” This statement is misleading. We know that extreme heat events are always a combination of weather variability and climate change. The statement the authors are making is that the weather variability component is not affected by climate change. That may be correct. However, this weather variability is occurring on top of a warmer climate, which makes the event more severe. In fact, the literature they cite themselves concludes that this event was made hotter by human-induced climate change. The authors should revise this statement to say that human-induced climate change made the event hotter.

Page: ix, Executive Summary

Comment type: Technical

Comment: The authors write “Global climate models generally run “hot” in their description of the climate of the past few decades – too much warming at the surface”. This is not correct. Eyring et al. (2021) assessed “The CMIP6 multi-model mean GSAT warming between 1850–1900 and 2010–2019 and associated 5–95% range is 1.09 [0.66 to 1.64] °C. Cross-Chapter Box 2.3 assessed GSAT warming over the same period at 1.06 [0.88 to 1.21] °C.

So some CMIP6 models simulate a warming that is smaller than the assessed observed range, and other CMIP6 models simulate a warming that is larger.” The executive summary should be revised to reflect that some global climate models warm less than observations, and that on average the CMIP6 models match observed warming well.

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Response to Section 8.2: Attribution methods

By Christopher Callahan, Ph.D., Indiana University

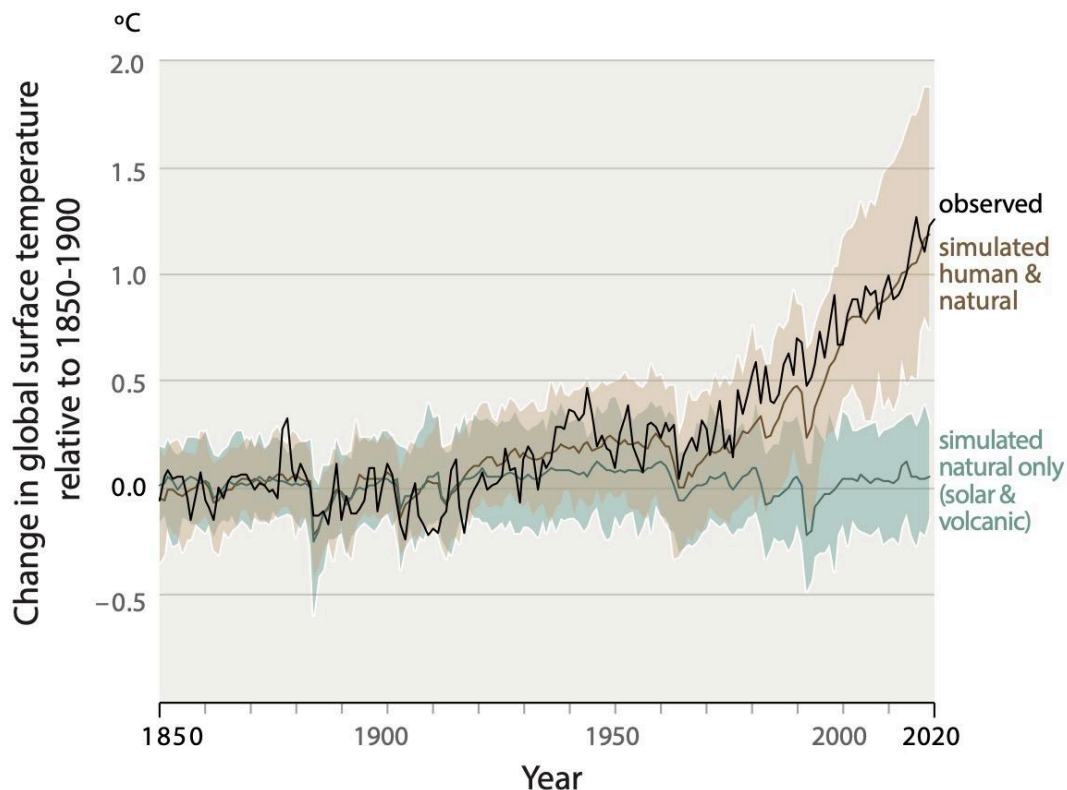
The section on **page 83** of the DOE CWG report outlines their perspective on methods used to attribute observed changes in the climate to human influence.

Comment: Editorial

The DOE CWG report outlines “optimal fingerprinting,” “time series analysis,” and “process-based attribution” as methods for attributing climate changes to anthropogenic influence (extreme event attribution will be left to a separate discussion). While each method is indeed used, the DOE CWG report neglects more simple and fundamental ways of understanding the human influence on observed climate change.

DOE neglects theory and early models. As early as the 1850s, Eunice Foote (1856) and John Tyndall (1861) developed the early science of the greenhouse effect. In 1967, Syukuro Manabe and Richard Wetherald developed the first iterations of computational climate models in radiative-convective equilibrium (Manabe & Wetherald, 1967). These models and the theory underpinning them led to the prediction, among others, that greenhouse gas forcing should warm the troposphere and cool the stratosphere. Observed patterns of tropospheric warming and stratospheric cooling confirm these predictions and cannot be comprehensively explained by mechanisms other than greenhouse gas forcing (Santer et al., 1996). A similar prediction has been borne out for extreme precipitation; the Clausius-Clapeyron relationship predicts that warmer air holds 7% more water vapor per K, and the observed increase in extreme rainfall globally has supported this prediction (Fischer & Knutti, 2016).

Coordinated climate model comparison enables attribution without specialized statistical techniques. Over several iterations, the Coupled Model Intercomparison Project has coordinated climate model experiments where models are run with all historically observed forcings, and with natural forcings only. It is straightforward to simply compare the time series of observed global temperature with these two groups of forcings. Figure SPM.1 in the IPCC’s Sixth Assessment Report (WGI) shows exactly such a comparison, reproduced below (IPCC, 2021). It is abundantly clear that natural forcings alone cannot explain the historical increase in global temperature.



Adapted by the author from panel (b) of Figure SPM.1, IPCC (2021). “Changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to Coupled Model Intercomparison Project Phase 6 (CMIP6) climate model simulations...of the temperature response to both human and natural drivers (brown) and to only natural drivers (solar and volcanic activity, green). Solid coloured lines show the multi-model average, and coloured shades show the very likely range of simulations.”

DOE neglects consilience across multiple lines of evidence. The IPCC has used multiple lines of evidence to arrive at the conclusion that human influence on the climate system is “unequivocal.” Fundamental theory and simple energy-balance calculations yield consistent estimates of human-caused radiative forcing, and changes in global sea level, the water cycle, the cryosphere, and other domains are only consistent with a human influence on the climate system (D. Chen et al., 2021). The strongest case for attribution is that there is *consilience* across many lines of evidence, instead of reliance on one method. These other lines of evidence are not discussed by the DOE CWG report. In the words of Trenberth (2011): “Humans are changing our climate. There is no doubt whatsoever.”

In order to effectively synthesize methods used for attribution, the DOE CWG report would need to discuss the theoretical basis for attribution and the role of coordinated climate model intercomparison, and it would need to outline how their selected types of attribution methods fit into the multiple-lines-of-evidence approach taken by the IPCC.

Response to Section 8.3.2: Optimal fingerprinting

By Christopher Callahan, Ph.D., Indiana University

This section addresses **pages 88 and 89** of the DOE CWG report. In this section, the DOE CWG discusses the “optimal fingerprinting” method of climate attribution, which uses linear regression techniques to establish whether observed warming patterns are consistent with anthropogenic or natural forcings. Typically, theory or climate models are used to establish a searched-for “fingerprint” that is characteristic of a particular type of climate forcing, such as the pattern of tropospheric warming and stratospheric cooling yielded by greenhouse gas forcing. The searched-for fingerprint is then convolved with climate observations to assess whether the observations exhibit the fingerprint above some level that might be explained by natural climate variability.

Comment: Reference

Pages 88 and 89 of the DOE CWG report cite four papers—all single-authored by one member of the CWG—to argue that some optimal fingerprinting approaches may not meet the Gauss-Markov conditions required for linear regression to be the best linear unbiased estimator. This line of criticism is primarily focused on the work of Allen and Tett (1999).

This section of the DOE CWG report presents a **misleading sample of the wide array of evidence on fingerprint-based attribution**. The CWG report cites four papers by one of the authors of the report, a reply by Chen et al. (2024), and the original Allen and Tett (1999) paper. They neglect (1) more recent developments in optimal fingerprinting; and (2) non-regression-based fingerprint attribution approaches.

- (1) Optimal fingerprinting did not end with Allen and Tett’s work. Significant further developments have advanced this field that are relevant to—but not cited by—the DOE CWG report. For example, a main critique leveled by McKittrick (2021) at the original work of Allen and Tett (1999) pertains to conditional invariance—i.e., that the expected value of the residuals conditional on the regressors is 0 ($E[u|X]=0$). One physical interpretation of this statement is that optimal fingerprinting assumes that anthropogenic forcing does not project onto internal variability; attribution studies must ensure that some component of the anthropogenic signal is not aliased into their estimate of natural variability (and vice versa). This issue has been the subject of extensive research. For example, Sippel et al. (2021) use a statistical learning technique to estimate anthropogenic fingerprints that explicitly protect against internal variability contaminating the forced signal. Recent work has also shown that the detection of human influence on global warming is not highly sensitive to how internal variability is characterized (Imbers et al., 2014).
- (2) A related but distinct approach to attribution uses pattern similarity methods to determine whether observations are growing more similar to the vertical or spatial pattern of temperature change characteristic of global warming (Ramaswamy et al., 2006; Santer

et al., 1996, 2003, 2018). Typically, the statistic of interest in these approaches is a simple centered or uncentered pattern correlation statistic (Santer et al., 1996). Several types of climate model simulations can additionally be used to determine whether the pattern similarity between observations and the fingerprint is statistically distinguishable from natural variability. Recently, it was shown that the degree of pattern similarity in observations is more than 5 standard deviations (“5 sigma”) greater than the range of natural variability, a degree of confidence equivalent to the gold standard in particle physics (Santer et al., 2019). While conceptually similar to the specific TLS approach critiqued by the DOE CWG report, this approach does not use the regression specification of Allen and Tett (1999), nor does it require estimating a regression coefficient and assessing whether it is consistent with unity.

Overall, the report does not treat optimal fingerprinting as a field worthy of surveying and evaluating. Instead, they cite a single paper from 25 years ago, four papers from one author of the DOE report, and no further evidence. To effectively review this literature, the DOE CWG report would need to evaluate how optimal fingerprinting has matured as a method, including the use of tools such as regularization and statistical learning, and place it in the context of other approaches to fingerprint-based attribution.

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Natural variability of large-scale ocean circulations

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This is a **technical comment** on the second subsection of Section 8.3.1 titled “Natural variability of large-scale ocean circulations (pp. 85-88).

In this subsection, the DOE CWG report discusses multi-decadal variability in the coupled atmosphere-ocean system and its impact on the overall trend in global surface temperature. The authors first imply that natural modes of variability in the ocean-atmosphere system are not properly accounted for in the attribution methods of integrated assessment reports such as the IPCC’s AR5 and AR6. They go on to discuss distinct periods over the historical record when natural variability may have impacted observed temperature trends.

Ultimately, this subsection fails to substantiate the claim at the top of Section 8.3 that the latest assessments of the role of internal variability in global warming are “inadequate”. Along the way, it commits several errors of interpretation and understanding, incomplete assessment of the scientific literature, and possible misquoting of IPCC reports.

To address concerns outlined in more detail below, the authors will need to:

1. Provide more relevant information on the assessment of internal variability in the scientific literature and IPCC reports and the methods used, and explain the specific issues that lead the authors to question its adequacy. In particular, the authors must show why they believe that the IPCC-assessed contribution of internal variability to historical warming ($\pm 0.2^{\circ}\text{C}$) needs to be increased.
2. Update their assertions about the representation of decadal timescale variability in climate models to include a wider swathe of the recent literature, as well as acknowledging the challenges in assessing this due to the short observational record and the key role for paleoclimate data and modeling in assessments of internal vs forced global temperature variability in recent centuries.
3. Include a discussion of the possible, and as yet undetermined, role of forcing in aliasing multi-decadal variability, particularly for Atlantic Multidecadal Variability.
4. Revise incorrect statements about (a) methodologies used to assess internal variability (e.g. relating to model averaging) and (b) the IPCC internal variability range (i.e. its erroneous interpretation as “peak-to-trough”).
5. Provide direct (chapter and subsection) citations for the quotes attributed to the IPCC AR5 and AR6. If these are not forthcoming, the quotations should be removed and

replaced with statements that accurately reflect the IPCC's assessment of, and confidence in, the impact of internal variability on the global warming trend.

6. Either (a) remove the discussion of individual time periods in the latter part of the subsection, which fails to address the role of internal variability in the long term trend, or (b) clearly acknowledge that these statements do not challenge the IPCC assessment of internal variability or the overall attribution of multi-decadal warming to human-induced causes, and considerably expand the discussion to include the instances in which the suspected role of internal variability was to suppress GHG-induced warming.

General comments

Mischaracterization of scientific literature on the impact of internal variability. That decadal-timescale coupled atmosphere-ocean variability impacts global mean temperatures is entirely uncontroversial and widely studied. The topic receives an abundance of attention in the scientific literature, including in both AR5 and AR6 (Bindoff et al., 2013; Eyring et al., 2021). It is a topic of ongoing debate and discussion (Mann et al., 2020; Klavans et al., 2025; Studholme et al., 2025; Barghorn et al., 2025), however the DOE CWG report's suggestion that the contribution of ocean circulation variability to the overall trend in surface temperatures has been missed, or otherwise under-represented in prior climate assessments, is demonstrably false. To meaningfully support their claim that the IPCC-assessed contribution of internal variability to historical warming ($\pm 0.2^{\circ}\text{C}$) is "inadequate", they need to provide a quantitative and comprehensive assessment of evidence that it should be higher.

Incorrect understanding of how internal variability is assessed in models and in integrated assessments. The DOE CWG report betrays a lack of understanding of how the impact of internal variability is evaluated in attribution studies and the IPCC reports. They note that (pp. 85-86), because in any given simulation the phasing of internal variability will be distinct, averaging across simulations removes the contribution of this variability. Indeed, this is the purpose of averaging simulations (as well as minimizing the effect of model structural uncertainty). No attribution study considers the evolution of the multi-model mean as providing a means of assessing internal variability. Rather, deviations of the observed time-series of warming from the multi-model mean often indicate the imprint of internal variability, as in the case of suppressed warming in the early 21st century (Kosaka and Xie, 2013) and over the satellite era (Po-Chedley et al., 2021, 2022). The contribution of internal variability is instead estimated from various factors including unforced model variability and its inter-model spread (Gillett et al., 2016; Parsons et al., 2020), large ensemble simulations (Christiansen et al., 2025), statistical assessment of the observational record (McKinnon and Deser, 2018), and proxy-derived temperature reconstructions (PAGES2k Consortium, 2019). It is a combination of these assessments that leads the IPCC AR6 to conclude their likely range of $\pm 0.2^{\circ}\text{C}$.

Irrelevant focus on specific periods of warming and cooling in the historical record. In the latter part of the subsection (pp. 86-88) the authors examine drivers of individual decadal or multi-decadal periods of warming and cooling. Their assessment focuses on specific time periods but does nothing to address or reconsider the attribution of the multi-decadal warming

trend, which is the purported aim of Chapter 8.3 (p. 84). It is the long term trend that is the salient feature of anthropogenic climate change and which is the focus of attribution studies and IPCC assessment reports. This human-induced warming is widely acknowledged to be overlain by periods of additional warming or cooling associated with internal natural variability in the coupled ocean-atmosphere system. As such, the author's statements are in no way controversial, and ultimately do not support their assertion at the top of Chapter 8.3 that there has been "inadequate assessment of natural climate variability".

Incomplete discussion of coupled model performance. The assertion (p. 85) that "most models have too little amplitude compared to observations at multi-decadal frequencies" is an over-simplification of the latest scientific understanding. In the first instance, assessing multi-decadal variability is challenging due to the relatively short observational record (Cassou et al., 2018) and the fact that these observations exist in a time of forced change (Brown et al., 2017). Nevertheless, comprehensive recent assessments of model performance with respect to ENSO and the PDO suggest that models actually exhibit low frequency variability of these modes (decadal and longer timescale) matching or exceeding observed variability (Fasullo et al., 2020; Parsons et al., 2020). Assessment of longer timescale modes, such as Atlantic Multidecadal Variability, is more challenging with the short observational record (Fasullo et al., 2020) but comparison to proxy-derived temperature reconstructions over the pre-industrial era indicate that many simulations exhibit comparable or greater variability on these timescales (PAGES2k Consortium, 2019). The DOE CWG report also neglects to highlight that the evaluation of model adequacy for the assessment of internal variability focuses not only on the period and amplitude of variability, but also its spatial pattern (Fasullo et al., 2020; Parsons et al., 2020; Eyring et al., 2021). Since the pattern of temperature change associated with GHG-forced global warming is uniquely distinct from that of the leading modes of internal variability, the pattern of overall trends can be used to detect and assess the contribution from each.

Absent discussion of the imprint of forcing in coupled ocean-atmosphere modes. Due to the relatively short observational period and the presence of forced change over this time, there is substantial debate about whether the Atlantic Multidecadal Oscillation represents a mode of internal ocean-atmosphere variability or if it reflects a response to trends in the forcing (Mann et al., 2020; Barghorn et al., 2025). Although debate continues, it is considered plausible or even likely that a substantial component of the Atlantic variability on multi-decadal timescales is driven by changes in regional forcing — namely aerosol loading and GHG-derived radiative forcing — which has been particularly pronounced over the North Atlantic over the last ~70 years decades. The DOE CWG report fails to discuss this central focus in recent literature, despite its evident relevance to the question of attribution.

Potential misattribution of IPCC summary statements. (p. 86) The DOE CWG produces two quotes that it claims to be summary statements from AR5 and AR6 from the IPCC. The quotes suggest that the IPCC reports conclude that the role of forced and natural variability are "difficult to disentangle" and thus that natural variability "contribute[s] to uncertainties in attributing observed changes to anthropogenic forcing". The citations for these quotes are not specific,

referencing the entire IPCC Working Group 1 reports. An exhaustive search in both AR5 WG1 and AR6 WG1 did not find these statements, or anything resembling them. They need to provide exact citations for these quotes. If they are not direct quotes, that needs to be fixed.

IPCC statements that *are* relevant to the impact and representation of internal variability include:

“Observed warming over the past 60 years is far outside the range of internal climate variability estimated from pre-instrumental data, and it is also far outside the range of internal variability simulated in climate models. Model-based simulations of internal variability are assessed to be adequate to make this assessment. Further, the spatial pattern of observed warming differs from those associated with internal variability. Based on this evidence, the contribution of internal variability to the 1951–2010 GMST trend was assessed to be likely between -0.1°C and 0.1°C , and it is virtually certain that warming since 1951 cannot be explained by internal variability alone.” (Stocker et al., 2013)

“Since AR5, the increased use of ‘large ensembles’ [...] supports improved understanding of the relative roles of internal variability and forced change in the climate system. Simulations and understanding of modes of climate variability, including teleconnections, have improved since AR5 (medium confidence), and larger ensembles allow a better quantification of uncertainty in projections due to internal climate variability.” (Arias et al., 2021)

Erroneous characterization of the IPCC internal variability range as “peak-to-trough”. The report notes (p. 86) that the IPCC assesses the likely contribution of internal variability to long-term warming to be $\pm 0.2^{\circ}\text{C}$. The authors incorrectly identify this as a “peak-to-trough” impact of internal variability, implying through this language that up to 0.4°C of the warming signal could be due to internal variability. However, the IPCC number means that they assess internal variability to explain *at most* 0.2°C of the observed warming, while finding it equally likely that it made the observed warming 0.2°C lower. The correct interpretation is that, had the phasing of the internal variability been different, the observed warming could have been up to 0.2°C lower or higher.

Misleading statement about relative role of internal variability vs. anthropogenic forcing over the last centuries. The report states that “Over many centuries, any global temperature changes from the troughs and peaks will cancel out, with little to no net impact.” This statement ignores what we definitively know about global temperature over the last many centuries from paleoclimate approaches: that late 20th century global warming exceeds the full range of global temperature variations from 1000-1800CE (Pages2K Consortium, 2019). Authors are encouraged to include a graph of reconstructed global temperatures, plotted with instrumental global temperatures (such as that shown below from the PAGES2K Consortium, 2019), in addition to the instrumental global temperature graphs they include.

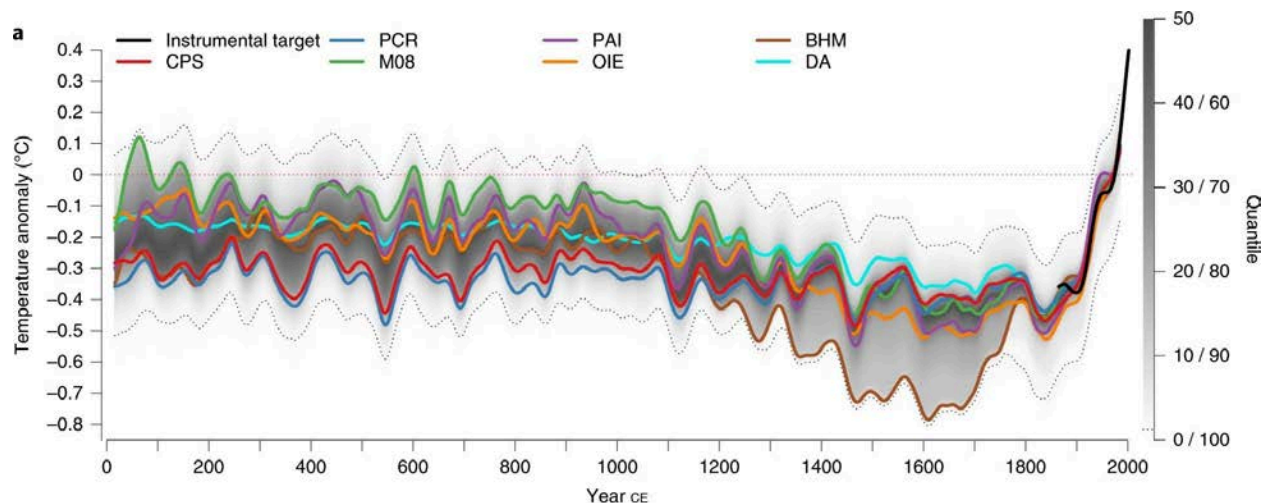


Figure caption from Figure 1 of PAGES2K Consortium, 2019: Global mean surface temperature anomalies with respect to 1961–1990 CE. The coloured lines represent 30 yr low-pass-filtered ensemble medians for the individual reconstruction methods. The grey shading shows the quantiles of all reconstruction ensemble members from all seven methods (right-hand y axis); the 2.5th and 97.5th percentiles are indicated with black dotted lines. The black curve is instrumental data for 1850–2017 CE from Cowtan and Ray, 2014.

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Response to Section 8.3.1

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This section is a **technical and editorial comment** on Section 8.3.1 “Solar Variability” of the DOE CWG report, beginning on **page 84 and continuing until page 85**.

In this section of the DOE report, the authors state on page 84, “However, the recommended forcing dataset for the CMIP6 climate model simulations used in AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017).” This is used to argue that it is possible for solar variability to be causing a significant amount of the modern warming.

Response:

First, the citation is not correct, it should be (Matthes **et al.**, 2017). This is the paper that provided the solar forcing timeseries for all CMIP6 model simulations (IPCC, 2021) (in the AR6).

Solar variability since 1850 and over the past millenia

It is correct that the long-term trend in TSI from Matthes et al. (2017) is on the low variability side, but this argument ignores that TSI data sets with more extreme trends (high variability trends; Lean et al., 1995 and Shapiro et al., 2011) are thought to be unrealistic (Wang and Lean, 2021) and are hence not used in model intercomparison projects such as PMIP3 (see Figure 1, blue curve). The IPCC (2013) states that “most recent reconstructions show a considerably smaller difference ($<0.1\%$) in TSI between the late 20th century and the Late Maunder Minimum (1675–1715) when the sun was very quiet, compared to the often-used reconstruction of Lean et al. (1995) (0.24%) and Shapiro et al. (2011) ($\sim 0.4\%$).”

In addition, IPCC (2021) explains that millennial-scale changes in TSI are within typical magnitudes of $1.5 [1.4 \text{ to } 2.1] \text{ W m}^2$ (C.J. Wu et al., 2018) and though extreme changes cannot be ruled out completely (Egorova et al., 2018; Reinhold et al., 2019), these likely did not happen over the past 9 kyr (see also Figure 2).

The statement, “However, the recommended forcing dataset for the CMIP6 climate model simulations used in AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017)” from the DOE report is also misleading since the CMIP6 model simulations for IPCC start in 1850 and hence do not include the Maunder Minimum (1645-1715). Therefore the (more extreme) secular trend of solar variability is not relevant for the period starting in 1850.

In Matthes et al. (2017) we provide a Maunder-Minimum-like case as an extreme future scenario and sensitivity experiment (see below for more details on this).

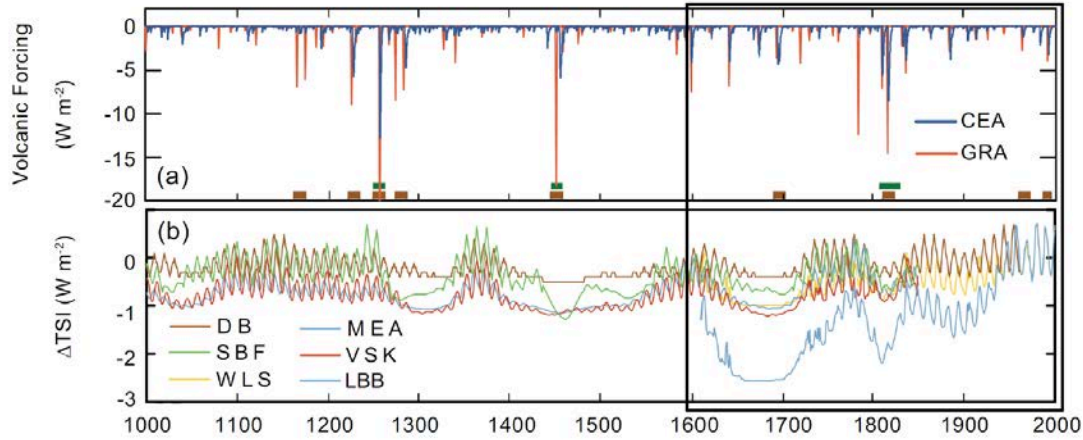


Figure 1: Overview of solar and volcanic forcing used in the Past Model Intercomparison Project 3 (PMIP3) simulations in support of the IPCC (2013) (AR5). All records except LLB (Lean et al., 1995) have been used in PMIP3 simulations. (Fig. 5.1 a,b from IPCC, 2013).

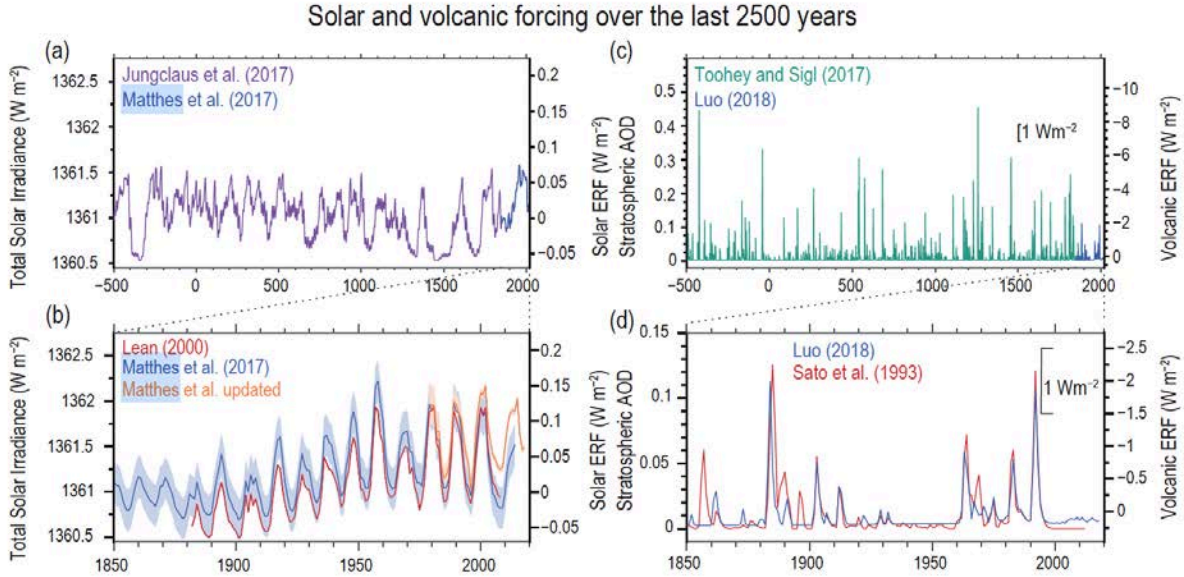


Figure 2: Overview of solar and volcanic forcing for the last 2500 years (a, c) and since 1850 (b, d) used in the Past Model Intercomparison Project 4 (PMIP4) simulations in support of the IPCC (2021) (AR6). (Fig. 2.2 from IPCC, 2021).

Solar variability over the satellite period

The four paragraphs on page 85 of the DOE report beginning with "While AR6 shows..." are misleading. They talk about the challenging reconstruction of TSI over time, in particular over the satellite period, but they ignore our community's work and efforts to reconstruct TSI and uncertainty estimates (Matthes et al., 2017).

In Matthes et al. (2017), we concluded the following (just as an example of mis-citation):

The sentence in the DOE report, "The choice of TSI satellite record used in an analysis can therefore substantially influence how much climate change is attributed to human versus natural forcings" is unsupported by the scientific literature. Over the last three solar cycles in the satellite era there is a slight negative TSI trend in the CMIP6 dataset (Figure 3).

A recent reconstruction of the TSI, with a proper estimation of its uncertainties, suggests that this downward trend between the solar minima of 1986 and 2009 is not statistically significant (Dudok de Wit et al., 2017). The TSI trend leads to an estimated radiative forcing on a global scale of -0.04 W m^{-2} , which is small in comparison with other forcings over this period. This is true regardless of which TSI dataset is chosen.

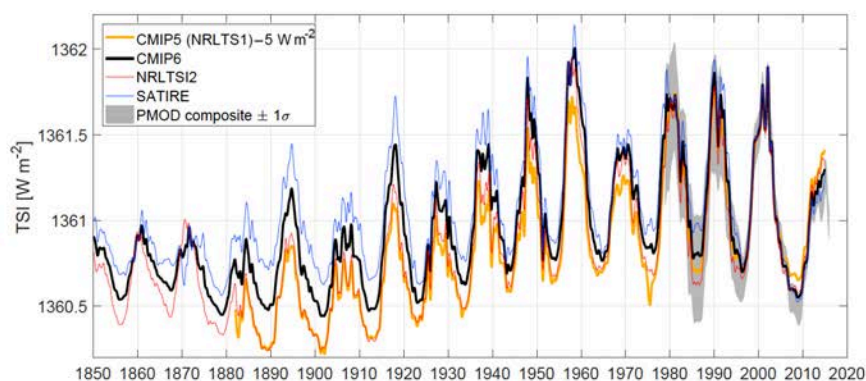


Figure 3: Comparison of several TSI solar forcing reconstructions used in CMIP5 (yellow) and CMIP6 (black). Also shown is the basis of the solar forcing CMIP6 reconstruction as well as the observational composite from PMOD with a confidence interval (Fig. 1 from Matthes et al., 2017).

Impact of a future solar Maunder-Minimum-like period

The statement "However, the recommended forcing dataset for the CMIP6 climate model simulations used in AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017)" is misleading in another way.

The IPCC model runs do not include the Maunder Minimum period (1645-1715), so differences in the TSI reconstructions during the Maunder Minimum are irrelevant for analysis of the modern period, starting in 1850.

The question that is relevant and important is: what would happen if the Sun would run into a Maunder-Minimum-like period in the future? This would have a cooling effect that

would counteract global warming. There are several studies that analyzed exactly this question (Meehl et al., 2013; Maycock et al., 2015). They consistently show that even a massive decrease of TSI by 0.25% over a 50-year period from 2020 to 2070 (Fig.1 from Meehl et al., 2013; left figure below), imposed in a future climate change scenario experiment, has a small impact on global warming (Fig. 2 from Meehl et al., 2013; right figure below). Once the solar minimum is over, the warming of global surface temperatures catches up to the reference simulation. Please note that the simulated decrease in TSI by 0.25% in Meehl et al. (2013) is much more than the uncertainty range in solar forcing reconstructions for CMIP6 in Figure 3.

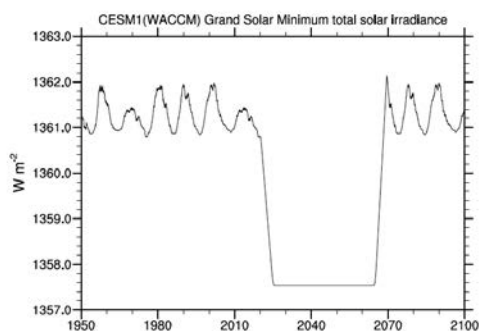


Figure 1. Time series of total solar irradiance input to WACCM showing a reduction of TSI from 2020 to 2070 with maximum reduced values of 0.25% from 2025 to 2065.

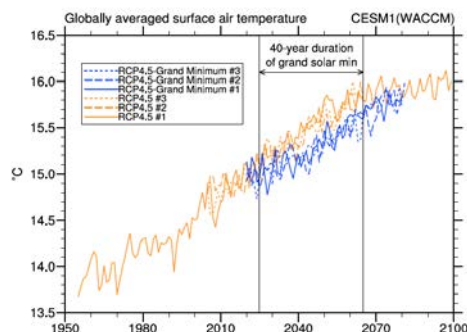


Figure 2. Time series of globally averaged surface air temperature anomalies (°C) relative to the 1986–2005 reference period for the WACCM standard RCP4.5 simulations (orange lines) and the grand solar minimum experiment (blue lines). The duration of the grand solar minimum experiment shown in Figure 1 is indicated from 2025 to 2065.

Solar indirect effects

The next completely wrong statement in the DOE report is on page 85, in the last paragraph in the Solar Variability paragraph: “Such solar indirect effects are not included in climate models, ...”. In Matthes et al. (2017) we provide for the first time ever a comprehensive dataset including TSI and solar spectral irradiance data as well as energetic particle forcing. We also provide an ozone dataset with the indirect effect included.

The solar spectral irradiance data, the energetic particle forcing and the ozone dataset are explicitly provided to include solar indirect effects in CMIP6 models. For the first time in the IPCC, many of the CMIP6 models do include solar indirect effects by using spectral solar irradiance as well as ozone changes. Some CMIP6 models even include particle effects for the first time.

Conclusions

In the above sections on solar variability since 1850 and over the past millennia, solar variability over the satellite period, impact of a future solar Maunder-Minimum-like period, and solar indirect effects, it is demonstrated that sound scientific evidence is misinterpreted or mis-cited, often leaving important details from Matthes et al. (2017)

out. By selecting which facts to amplify, and by citing only one or two papers (e.g., Scafetta et al., 2023) without the context of the full scientific literature and “simplifying it”, the conclusions they draw are simply wrong.

Instead, model simulations for AR6 are the most comprehensive set of experiments, including direct and indirect solar effects on climate. The last sentence in the section “Solar Variability” on page 85 “However, claims of non-TSI mechanisms influencing climate are uncertain and debated” is nonsense and demonstrates that the authors of the DOE report did not read the literature, even those papers that they cited (e.g., Matthes et al. 2017). To conclude, we demonstrated that solar variability cannot be causing a significant amount of modern warming.

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Response to section 8.3.1

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This section is a **technical comment** on Section 8.3.1 of the DOE CWG report, beginning on **page 84**.

Overall, this section overemphasizes uncertainty and claims an inadequate assessment of natural climate variability in IPCC AR6, whereas we do know with high certainty that anthropogenic greenhouse gas emissions have caused the global warming over the last 50-100 years. There are no credible forcings other than greenhouse gases that could have caused that warming.

Temperature measurements in the ocean show that the ocean is warming from the top down, which is inconsistent with a role of ocean circulation in causing atmospheric warming (Barnett et al., 2005; Cheng et al., 2020). Energy conservation requires that, if ocean circulation had caused surface warming, there must be cooling in the subsurface. However, this is not observed. The ocean has warmed at all depth, most at the surface, a pattern that is consistent with anthropogenic warming. This should be mentioned in the part entitled “Natural Variability of Large-Scale Ocean Circulation”, otherwise this part is misleading.

Since AR5, there has been increasing and robust evidence that external forcings—including anthropogenic greenhouse gases and aerosols, as well as natural volcanic aerosols—have modulated the Atlantic Multidecadal Oscillation over the historical period, as assessed in AR6 WGI Section 3.7.7. This important aspect is completely overlooked in Section 8.3.1. Evidence that multi-decadal trends in the Pacific Decadal Oscillation have been anthropogenically forced (Klavans et al., 2025) should also be discussed in this context.

Although state-of-the-art climate and Earth system models tend to underestimate natural internal climate variability, single-model initial-condition large ensembles have provided a pathway to better quantify its range. Using several such ensembles, AR6 WGI Box 4.1 assessed that the 5–95% ensemble range of annual mean global surface

air temperature is approximately ± 0.25 °C (MIROC6, IPSL-CM6A), spanning from about ± 0.2 °C (CanESM5) to ± 0.3 °C (EC-Earth3). This model-based estimate is consistent with observation-based estimates.

The following text on page 88 in this section is therefore misleading: “When the Great Pacific Climate Shift is accounted for in climate attribution analyses since 1950, 40 percent or more of the warming in the second half of the 20th century is attributed to natural internal variability (McLean et al., 2009; Tung and Zhou, 2013; Chylek et al., 2016; Scafetta, 2021)”. There are three problematic aspects in this text. **First, the argument relies exclusively on Tung and Zhou (2013) and is not fully supported by the other three cited references.** Specifically, McLean et al. (2009) and Scafetta (2021) provide no quantitative estimates of the contribution of internal variability to the warming trend. Moreover, the estimate presented in Chylek et al. (2016) is substantially lower than that of Tung and Zhou (2013). According to Chylek et al. (2016), the contribution of the Atlantic Multidecadal Oscillation (AMO) to the 1970–2005 warming was between 0.13 and 0.20 °C (depending on the AMO index used), compared with a greenhouse gas contribution of 0.49–0.58 °C.

Second, while Figure 4 of Tung and Zhou (2013) suggests that internal variability may account for approximately 40% of the observed global warming over the past 50 years, it does not contribute significantly to the long-term warming trend over periods exceeding 75 years. This interpretation is consistent with the AR6 assessment (Section C.1, WGI SPM), which states: “Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes.”

Third, the statement does not acknowledge the ongoing debate regarding the role of external forcings in driving AMO variability. Recent studies have highlighted that what has traditionally been interpreted as an internally generated oscillation may, at least in part, reflect externally forced variability, thereby complicating the estimation of the contribution of internal variability to global warming when relying solely on statistical analyses of observational data.

To correct this, the following changes must be made in the DOE CWG document:

- Revise the statements that claim an inadequate assessment of natural climate variability by IPCC AR6. IPCC AR6 lists extensive peer-reviewed literature that led to the following assessment: “When estimated over the entire historical period (1850–2020), the contribution of natural variability to global surface warming of -0.23 °C to $+0.23$ °C is small compared to the warming of about 1.1 °C observed

during the same period, which has been almost entirely attributed to the human influence.”

- Include evidence from ocean warming pattern, which is inconsistent with changes in ocean circulation causing the observed global warming, but which is consistent with anthropogenic warming causing heat entering the ocean from above.
- Include the growing body of robust evidence that external forcings have modulated the Atlantic Multidecadal Oscillation over the historical period, which has important implications for attributing recent trends to natural internal variability.
- Include a more comprehensive assessment of the contribution of natural climate variability to the global warming trend, as in IPCC AR6 reports.

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Section 8.3.1: Solar variability

Dr. Theodosios Chatzistergos¹ and Dr. Ted Amdur²

This section is a **technical comment** in response to Section 8.3.1 (pg. 84-85) of the DOE CWG report, specifically the subsection titled “Solar variability.” We, Theodosios Chatzistergos and Ted Amdur, submit these comments in our personal capacity as concerned scientist stakeholders working in academia and industry, respectively. As scientists, we are concerned about the quality and representation of scientific literature in the Climate Working Group report and how such report will be used to inform the Environmental Protection Agency’s (EPA) proposal to repeal the 2009 Endangerment Finding under Section 202(a) of the Clean Air Act (CAA), allowing EPA to prescribe standards for greenhouse gas emissions.³

Because of our unique position as experts on solar variability, with specialized knowledge of the academic literature on this topic, we feel compelled to clarify the record’s depiction of the current best available science, which is a cherry-picked subset of the available literature that is evidently selected for their conclusions, rather than the studies’ quality, sophistication, rigor, or prescience. In the following sections, we begin by outlining the overarching flaws in the “Solar variability” subsection of the CWG Report. We then assert a series of rebuttals to specific claims made in the report that are not, and cannot be, substantiated by the current state of the scientific literature.

To correct these technical flaws, the following changes must be made in the DOE CWG report:

- **Review and include best available scientific literature**, specifically literature showing that between Maunder minimum and present, solar influence on Earth’s climate has had a net effect far smaller than known anthropogenic effects.
- **Discontinue reliance on verifiably flawed and unrepresentative literature.** The report must discontinue reliance on and remove references to studies known to be invalid and methodologically flawed, due to the use of cherry-picked data, outdated and physically

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³<https://www.epa.gov/newsreleases/epa-releases-proposal-rescind-obama-era-endangerment-finding-regulations-paved-way>

implausible models, and statistical methods that have been discredited in the peer-reviewed literature (e.g., Connolly et al. 2021; Stefani 2021). The deliberate inclusion of such unrepresentative, flawed, and discredited studies--while ignoring the vast body of countervailing evidence in available literature--constitutes a failure to use the **best available science** and renders the report's conclusions arbitrary.

- **Accurately contextualize the impact of non-TSI solar forcings based on the weight of evidence.** The report must be revised to accurately represent the current scientific understanding of non-TSI mechanisms, which shows that their influence on global climate is minor. Instead of presenting highly speculative or largely refuted mechanisms (like the link between galactic cosmic rays and clouds) as significant and unresolved debates, the report must include the key **constraining evidence** from major experimental and modeling efforts (e.g., Pierce 2017 on the CERN CLOUD experiment) that place upper bounds on their potential effects. Presenting only the arguments for a large effect, while omitting the strong evidence against it, creates a biased and indefensible record.
- **Acknowledge and incorporate established physical constraints.** The report must be revised to incorporate the known physical constraints on long-term Total Solar Irradiance (TSI) variability, as established in studies such as Yeo et al. (2020). Any discussion of "high variability" scenarios that contradict these established physical upper bounds are fundamentally irrational and must be removed because they rely upon physically unrealistic scenarios.
- **Accurately represent consensus scientific reports.** The text must be corrected to accurately represent the findings of the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports. This includes clearly distinguishing between concepts like Total Solar Irradiance (TSI) changes, Radiative Forcing (RF), and Effective Radiative Forcing (ERF). The misleading claim that IPCC AR6 shows a "substantially greater solar impact" than AR5 must be corrected to reflect that their radiative forcing estimates are, in fact, broadly consistent.
- **Substantiate all claims with correct and relevant citations.** Vague, unsubstantiated phrases such as "growing evidence" must be removed and replaced with specific citations to high-quality, peer-reviewed literature. Furthermore, all citations must be verified for accuracy, correcting erroneous references to non-existent studies, such as "Scafetta et al. (2023)". Such reliance on non-existent evidence is an arbitrary analysis.
- **Address and resolve known data discrepancies, rather than merely highlighting them.** Rather than presenting historical data disputes such as the "ACRIM-gap" as a major unresolved issue that undermines the entire observational record, the report must incorporate the recent scientific literature (e.g., Amdur and Huybers 2023; Chatzistergos et al. 2025) that has largely resolved this discrepancy. Presenting a resolved issue as a source of major uncertainty is misleading and fails to reflect the best available science.
- **Apply causality tests uniformly.** The report advocates for the use of sophisticated causality tests to evaluate mainstream climate science. It must therefore apply these same tests to the alternative studies it cites (e.g., Scafetta 2013, Stefani 2021). Failing to apply its own stated standards of evidence consistently and even-handedly is definitionally arbitrary.

I. Overarching Flaws

1) An unsubstantiated claim that there exists "inadequate assessment of natural climate variability"

Page: 84

Comment type: Technical

Comment: On page 84 of the DOE CWG report, the authors identify “three areas of substantive criticism of the IPCC’s assessment of the causes of recent warming,” which are the “inadequate assessment of natural climate variability, inappropriate statistical methods, and substantial discrepancies between models and observations.” The report implies that solar variability, as a form of natural climate variability, has been inadequately assessed by the IPCC, calling into question the IPCC’s conclusion that the majority of planetary warming can be attributed to anthropogenic climate change.

We first note the rhetorical sleight of hand being practiced in this section. The DOE CWG report claims it will review the “scientific certainties and uncertainties in how anthropogenic carbon dioxide (CO₂) and other greenhouse gas emissions have affected, or will affect, the Nation’s climate, extreme weather events, and selected metrics of societal well-being.” (pg. ix). While the UN IPCC draws from a wide spectrum of the climate science literature, critiquing the editorial choices of the text within the IPCC reports does not bear upon the state of the science itself. There exists a diverse array of scientific literature to answer the authors’ questions, if they look outside the IPCC reports’ text to the studies cited in the IPCC reports, as well as other published papers. Indeed, much of the perceived lack of discussion of natural climate variability in the IPCC reports is precisely because so much literature has been produced to refute the claims of the DOE CWG report authors, and over so long a time period, that these claims are no longer part of the active scientific debate and are thus given only brief note in the most recent IPCC Assessment reports.

Taken as a whole, this claim of “inadequate assessment” is reminiscent of someone claiming a tool needed for a job doesn’t exist because they failed to find the correct aisle at the hardware store.

In points 3, 4, 5, and 8 of this comment, we will provide specific examples of how questions of natural climate variability, and specifically solar variability, that were raised by the authors have been carefully and thoroughly addressed by recent scientific studies.

2) Inconsistent standards of scientific merit

Pages: 84-90

Comment type: Technical

Comment: In Section 8.3.1 of the DOE CWG report, extensive discussion is made of how natural variability of large-scale ocean circulations, as well as inappropriate statistical methods, call into question the mainstream scientific attribution of planetary warming to anthropogenic versus natural causes. They argue that climate model studies are challenged in resolving multi-decadal fluctuations in ocean circulation that can affect global mean surface temperatures over many decades, and that more sophisticated statistical methods of assessing causality are needed to determine the relative roles of anthropogenic and natural roles in climate change.

Based upon these same standards, however, none of the studies cited in the “Solar variability” section as evidence of an increased role for solar variability in climate would survive scrutiny (Scafetta, 2013; Stefani, 2021; Scafetta et al., 2023 [sic]). While there exist differences in the respective methods of these papers, all three share common characteristics that the DOE CWG report authors regard as methodological flaws in the same section:

- 1) These statistical studies fail to consider variability of large-scale ocean circulations with any sophistication, either ignoring the contribution (Scafetta, 2013) or making the unsubstantiated claim that using astronomical or solar records to explain global temperatures inherently captures the behavior of ocean circulation variability, as ocean circulation variability is itself controlled by

these extraterrestrial factors (Stefani, 2021; Scafetta, 2023). This circular reasoning begs the question.

- 2) These studies repeat statistical approaches that have long been known to be methodologically flawed (Richardson and Benestad, 2022), and come nowhere close to the sophistication called for by the DOE CWG report authors for the papers they hold in doubt. Scafetta and co-authors have attempted many statistical undertakings to demonstrate the primacy of solar variability in controlling global temperatures, and while the specifics have varied, those studies, including the two cited here, are subject to the general concerns raised by Benestad and Schmidt (2009) in a careful evaluation of one of the many Scafetta et al. approaches. One objection by Benestad and Schmidt (2009), which is relevant to the three studies cited by the DOE CWG authors, is the following:

We have also shown through the regression exercises that neglecting important forcings may inflate the climate sensitivity estimates since colinearity between different forcings interferes with the estimation of the sensitivity to each other.

To restate this concern in plain terms, records of solar variability can share the same trends as other variables that affect climate, including greenhouse gas emissions and aerosol emissions, thus a statistical analysis such as regression that inputs each variable without any context is liable to confuse the attribution of temperature between true causes and lookalikes. All three studies noted here from this subsection of the DOE CWG report perform a form of regression analysis that do not include all relevant variables (such as ocean circulation-induced variability, as noted in point A), and thus are at risk of this statistical error. Ironically, these studies also fail to validate their claims by employing the causality tests that are advocated for by the authors just a few pages later in 8.3.1 (pg. 88 - 90).

When high standards are held for a subset of scientific studies, while those exact same standards are not held for another subset, and when the only consistent distinguishing feature between the two subsets appears to be the normative direction of the studies' findings (broadly supporting or refuting the salience and impact of anthropogenic climate change), we are led to conclude that this section begs the question and uses a cherry-picked, distorted view of the available literature to reach the stated conclusions.

II. Specific Rebuttals

3) The authors cite studies that rely upon solar variability scenarios that have been demonstrated to be physically unrealistic

Page: 85

Comment type: Technical

Comment: In the following passages on page 85 of the DOE CWG report, the authors make claims that require there to exist a spectrum of potential histories of solar variability, from low to high:

While AR6 shows a substantially greater solar impact than does AR5, the overall impact of solar forcing on the climate was still assessed to be small compared to anthropogenic forcing. However, the impact of solar variations on the climate is uncertain and subject to substantial debate (Lockwood, 2012; Connolly et al., 2021) - something that is not evident in the IPCC assessment reports.

This uncertainty causes some reconstructions of TSI from 1750 to have low variability (implying a very low impact of solar variations on global mean surface temperature) whereas datasets with high TSI variability can explain more than 70 percent of the temperature variability since preindustrial times (Scafetta, 2013; Stefani, 2021). The choice of TSI satellite record used in an

analysis can therefore substantially influence how much climate change is attributed to human versus natural forcings.

This narrative, however, is invalidated by the scientific reality that the high solar variability scenarios cited here have been shown to be physically unrealistic. In a 2020 paper titled “The Dimmest State of the Sun”, Yeo et al. establish an upper bound on how much total solar irradiance (TSI) could have varied between now and the Maunder Minimum, finding an upper bound limit of TSI change of **2.7 W/m²** through a physical model constrained by state of the art solar imagery and the known physics of the Sun. It is important to note that the Yeo et al. 2020 constraint is about the dimmest possible state of the Sun without specific claim for the Maunder minimum and it is very likely that Maunder minimum did not reach this dimmest state. Separately, Rempel (2020) finds that even if the quiet-Sun/small-scale magnetic field could vary in ways that have been unobserved, the high variability scenarios used in the papers cited by the DOE CWG report would be “unrealistic” by requiring a 50% reduction in the quiet magnetic field strength in the past.

It is a straightforward misrepresentation for the authors to elide these studies when discussing solar variability scenarios, as they provide a straightforward explanation for why a higher degree of solar variability is not discussed extensively in the most recent IPCC assessment report.

4) The studies cited by the report authors suffer from critical methodological flaws

Page: 85

Comment type: Technical

Comment: In this comment, we detail the critical methodological flaws exhibited by two papers cited by the DOE CWG report authors as evidence of past solar variability large enough to explain the majority of the historical global temperature record and as evidence that such a causal explanation of global temperatures due to solar variability can be inferred from statistical study.

We begin with Connolly et al. (2021), which provides demonstration of how the high solar variability scenarios, in contradiction to known physical constraints, are constructed from flawed methodologies.

Connolly et al. 2021 cherry-picked a set of 16 TSI series, deliberately balancing the sample to include eight with low long-term variability and eight with high variability. To achieve this equal division, they included outdated or superseded versions of some models, while they ignored many low variability TSI reconstructions. We note this cherry-picking in Chatzistergos et al. (2023), which states: “often older versions are used in the literature ignoring the fact that newer versions, overriding the earlier ones, are available. We caution against using outdated reconstructions.” Connolly et al. 2021 did not clarify how the division between high and low variability series was done, but all high variability series they used lie outside the constraint imposed by Yeo et al. (2020) that there does not exist a physical basis for assuming that TSI variability can exceed **2.7 W/m²** versus present day.

The high variability group in Connolly et al. 2021 includes:

- **Hoyt and Schatten (1993)** The Hoyt and Schatten (1993) model has been shown to be highly unrealistic and is now widely discredited, as discussed in detail in our prior comment (Chatzistergos, 2024). As detailed in Chatzistergos (2024), it contains multiple arbitrary adjustments and fabricated data for one index spanning over a decade, apparently copied from another index. Crucially, its high variability was imposed by the authors rather than emerging from the model itself. When updated sunspot indices for updating the model and direct TSI composites

(e.g., PMOD, Montillet et al. 2022, ACRIM) are used, it becomes clear that Hoyt and Schatten (1993) exaggerated TSI variation amplitudes by roughly a factor of five.

- **Lean et al. (1995)** An early and now outdated version of the NRL model. It has long been superseded by newer versions, latest by NNL.
- **Bard et al. (2000)** reconstructed TSI by applying a simple linear scaling to the production rates of cosmogenic isotopes (e.g., ^{10}Be), without accounting for nonlinear effects such as geomagnetic modulation, (Usoskin 2023). More recent and physically realistic models, such as **SATIRE-M** (Wu et al. 2018), explicitly incorporate this and indicate substantially lower long-term TSI variability. Furthermore, Delaygue and Bard (2011) revised the original Bard et al. (2000) reconstruction downward, but Connolly et al. (2021) ignored this update.
- **Shapiro et al. (2011)** an older version of Egorova et al. 2018
- **Egorova et al. (2018)** Connolly et al. 2021 included this model four times (five considering the Shapiro et al. 2011 too) as distinct reconstructions. The Egorova et al. (2018) model relies heavily on assumptions about the Sun's quietest possible state, a critical and uncertain input. This approach has been strongly criticized by Yeo et al. (2020), who demonstrated that the long-term TSI variability in the Egorova et al. 2018 model is exaggerated.

Over recent decades, our irradiance modeling capabilities have improved dramatically. For example, Shapiro et al. (2017) and Yeo et al. (2017), using the state-of-the-art physics-based modeling in the SATIRE-3D model, demonstrated that we can reproduce TSI measurements with exceptional accuracy across all measured timescales without the need for any adjustments or free parameters in the model. Thus, there is no valid motivation for an arbitrary adjustment to a solar variability reconstruction due to a model-data mismatch. Additionally, there have been significant advances in the analysis and compilation of solar data (Clette et al. 2023; Chatzistergos et al. 2024) needed for irradiance reconstructions. These improvements, along with enhanced modeling and new high precision direct irradiance measurements (Kopp 2025), have significantly advanced our understanding of solar irradiance variability. The current consensus is that the secular trend in irradiance variations is relatively small. The extent of this trend is further constrained by Yeo et al. (2020), a study that, as mentioned in the prior comment, established a robust constraint on the Sun's dimmest state, the lowest expected TSI value, to be **2.7 W/m²** below the 2019 minimum.

An additional important point is that in all 8 high variability models shown by Connolly et al. 2021, the long-term TSI variability was not derived from observational constraints but was instead imposed as a model assumption. Modern updates of the NRL model (Coddington et al. 2019; Lean 2018) and Hoyt and Schatten 1993 (Chatzistergos 2024) have shown that the high variability that was imposed in the earlier versions is inconsistent with direct TSI measurements and have therefore been revised to show lower variability. Richardson and Benestad (2022) have also criticized the methodology used by Connolly et al. (2021) to attribute temperature changes to TSI.

Another point about the misleading presentation of our current understanding on long-term changes in irradiance made by Connolly et al. (2021) was presented by Chatzistergos et al. (2023). Chatzistergos et al. (2023) collected most (if not all) available reconstructions of total solar irradiance (TSI) that cover the period 1700-1986, grouping different versions of individual models together. They found 24 groups of models, out of which 21 suggest a rather small secular trend (here defined as difference between activity minima in 1986 and 1700) that is between -0.09 and 2.2 Wm^{-2} . Only 3 groups of models were found to exhibit a high secular trend (Hoyt and Schatten 1993; Egorova et al. 2018; Fligge and Solanki 2000). As noted in Chatzistergos et al. (2023), the study by Fligge and Solanki 2000 is "considered replaced by the newer SATIRE-family models".

Overall, despite the uncertainty in estimating the secular trend in TSI variations, current models suggest a relatively weak secular trend, and all high variability models have been criticized or even rendered invalid (in the case of Hoyt and Schatten (1993)). While old versions of models that were at some point suggesting high secular trends, have been typically revised and now exhibit low secular trends. Connolly et al. (2021) significantly overstates the Sun's role in recent climate change by selectively including outdated, superseded, and implausible TSI reconstructions that are inconsistent with modern observational and theoretical understanding. Chatzistergos et al. 2023 also states: "often older versions are used in the literature ignoring the fact that newer versions, overriding the earlier ones, are available. We caution against using outdated reconstructions."

Turning to Stefani (2021), we do not believe this paper represents the best available science when it includes fundamental methodological flaws that were directly identified in the Sun-climate literature decades ago (Pittock, 1978; Benestad and Schmidt, 2009). We outline three critical flaws in the Stefani (2021) study.

First, they create a hypothesis to fit the facts. We quote extensively from Pittock (1978), a review paper that responds to Sun-climate papers from 50+ years ago with the same flaws seen in Stefani (2021): "One of the greatest temptations when one is faced with facts which do not fully support a hypothesis is to elaborate the hypothesis so as to fit the facts." Here, Stefani (2021) explicitly chose to associate the geomagnetic aa-index with global sea surface temperatures not because that is the most logical predictor between the Sun and Earth's climate, but because it presents a strong match between a solar record and certain Earth temperature records. Pittock (1978) states the danger of such an approach: "The problem with this sort of reasoning is that almost any hypothesis can be made to fit a given set of observations if it is elaborated until it contains enough degrees of freedom. If this is done after an examination of the observational data, the new complex hypothesis can only be tested by comparing new qualitative or quantitative predictions against new or independent data".

Second, they performed a regression analysis without all relevant data. Stefani (2021) uses only two datasets to attempt to predict global temperatures: the geomagnetic index, and a version of the CO₂ record. As we noted in our second comment, this approach has been thoroughly discredited by Benestad and Schmidt (2009):

We have also shown through the regression exercises that neglecting important forcings may inflate the climate sensitivity estimates since colinearity between different forcings interferes with the estimation of the sensitivity to each other.

To restate this concern in plain terms, records of solar variability can share the same trends as other variables that affect climate, including greenhouse gas emissions and aerosol emissions, thus a statistical analysis such as regression that inputs each variable without any context is liable to confuse the attribution of temperature between true causes and lookalikes.

Third, Stefani (2021) applies smoothing--through the use of a moving average--to their regression analysis without proper consideration of the statistical thorniness that this move entails. Again, this approach is a known pitfall for statistical analyses in the Sun-climate literature that was expounded upon by Pittock (1978) almost 50 years ago as leading to an inordinate number of false positives:

...smoothing of climatological series leads to a significant reduction in the number of degrees of freedom applicable to computed correlations between climatological and sunspot data. This leads

to much greater variability in the computed correlation coefficients, more frequent high values occurring by chance.

We acknowledge that if these two citations are removed, the DOE CWG authors could replace them with entries from a subset of the peer-reviewed literature that would conclude nearly identical findings. These examples of flawed methodology should be understood as illustrations of a recurring **pattern of error**—including cherry-picking, violating physical constraints, and improper statistics—found in a specific subset of the Sun-climate literature. Substituting these citations with functionally identical papers would demonstrate that the report's selection process is predisposed to a particular conclusion, rather than an objective assessment of evidence. A credible revision must actively screen for and exclude studies exhibiting this pattern of flawed methodology.

5) Non-TSI mechanisms of the Sun affecting climate have been studied in depth and are unnecessary to explain the observational record

Page: 85

Comment type: Technical

Comment: The DOE CWG report concludes the “Solar Variability” section with the following paragraph:

There is growing evidence that other aspects of solar variability, which are referred to as solar indirect effects, either amplify TSI forcing or are independent of TSI forcing. Scafetta et al. (2023) suggests that ~80 percent of solar influence on climate might stem from non-TSI mechanisms. There are numerous candidate processes, including solar ultraviolet changes; energetic particle precipitation; atmospheric-electric-field effect on cloud cover; cloud changes produced by solar-modulated galactic cosmic rays; large relative changes in the magnetic field; and the strength of the solar wind. Such solar indirect effects are not included in climate models, although indirect methods of estimating their impacts suggest they are significant. However, claims of non-TSI mechanisms influencing climate are uncertain and debated.

Nearly every claim in this paragraph is without citation and unsubstantiated. This includes claims of “growing evidence” of the importance of solar indirect effects and that “indirect methods of estimating their impacts suggest they are significant”. Additionally, many of these claims are imprecise to the point that, despite our expertise, we cannot make clear sense of the claim. For example, “large relative changes in the magnetic field” could refer to any number of variations in either the solar or Earth magnetic field. We also struggle to be sure of how to respond to the only citation provided, as there exists no “Scafetta et al. (2023)” paper, and in this comment we surmise that the authors intended to refer to Scafetta (2023), which we respond to below.

That said, we can provide expertise to respond to the claims of the authors. Amdur et al. (2021) was a study undertaken to test the claim that “solar indirect effects are not included in climate models, although indirect methods of estimating their impacts suggest they are significant.” Amdur et al. agreed with the authors that it would be important to understand whether or not climate models are missing an important control on the climate system, and at the time there appeared to be some difference between the magnitude of climate model response to solar variability versus the response to solar variability in the observed temperature record. Through an extensive statistical analysis of existing methods for estimating the indirect impact of solar variability, as well as a thorough methodological approach to compare models and data under 48 combinations of observed datasets, they concluded that, “whereas additional

processes have been proposed to amplify the climate response to solar cycle forcing, observations of the global temperature response to solar forcing are found to be in keeping with standard general circulation model simulations” and that the entirety of the observed differences could be ascribed to quirks with the underlying data or statistical methods.

Importantly, other independent approaches to statistically estimating model versus observed response to solar variability have reached the same general finding (Misios et al. 2016, Li and Tung 2023), and we are unaware of approaches with a similar level of statistical sophistication finding a demonstrable difference between model and observation, let alone the 5x mismatch between modeled and observed climate response to solar variability implied by the DOE CWG report authors and Scafetta (2023), which notably includes responses to solar cycle variability that are far out of line with the findings of Misios et al. (2016), Amdur et al. (2021), and Li and Tung (2023).

Given the inherent agreement observed between models and observations, the “numerous candidate processes” listed by the authors are solutions in search of problems. Many of these processes have been thoroughly vetted and excluded individually, however, making their repetition here a “zombie argument” that is inconsistent with the state of the best available science. For example, the effect of cosmic rays on cloud formation has been shown to have negligible effects based on the CLOUD experiment at CERN (Pierce 2017). Effects on Earth’s atmosphere for some of the other processes have been presented in the literature, e.g. Mironova et al. 2015 and Sinnhuber & Funke 2020, although their effects are not found to be as significant relative to solar irradiance variations as implied in the DOE CWG report.

6) Confusion between range of temperature changes due to natural forcings and net effect;

Page: 84

Comment type: Technical

Comment: The DOE CWG report states:

AR6 states that natural external drivers since 1850-1900 have changed global surface temperature by -0.1°C to $+0.1^{\circ}\text{C}$, and internal variability has changed it by -0.2°C to $+0.2^{\circ}\text{C}$ – on average having essentially no net impact on the warming since 1850-1900.

The AR6 WGI report presents this in Fig. SPM.2 as “Aggregated contributions to 2010–2019 warming relative to 1850–1900.” This figure refers to the net effect of various climate drivers on global surface temperature between these two periods, not the maximum changes observed. The accompanying range represents the uncertainty in these estimates. It is therefore misleading to claim that AR6 asserts natural drivers have changed global temperature by $\pm 0.1^{\circ}\text{C}$ since 1850–1900. In reality, Fig. SPM.1 shows that natural variability has led to global temperature fluctuations of up to $\pm 0.5^{\circ}\text{C}$ on annual resolution, but the net contribution of natural drivers to long-term warming is estimated at around $\pm 0.1^{\circ}\text{C}$.

7) Confusion between radiative forcings in AR5 and AR6

Pages: 84-85

Comment type: Technical

Comment: The authors of the DOE CWG report potentially conflate two related but distinct concepts: radiative forcing and TSI differences, which were both mentioned in section 8.3.1 but not clearly distinguished.

The relevant text in the DOE CWG report is the following:

AR5 concluded that the best estimate of radiative forcing due to Total Solar Irradiance (TSI) changes over the period 1750–2011 was very small (0.05 W/m^2 , Myrhe et al., 2014). AR6 acknowledges substantially higher values and a much larger range of estimates of changes in

TSI over the last several centuries, stating that the TSI between the Maunder Minimum (1645–1715) and the second half of the twentieth century increased by 0.7–2.7 W/m², a range that includes both low and high variability TSI data sets (Gulev, 2021). However, the recommended forcing dataset for the CMIP6 climate model simulations used in AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017). While AR6 shows a substantially greater solar impact than does AR5, the overall impact of solar forcing on the climate was still assessed to be small compared to anthropogenic forcing. However, the impact of solar variations on the climate is uncertain and subject to substantial debate (Lockwood, 2012; Connolly et al., 2021) – something that is not evident in the IPCC assessment reports.

However, AR6 WGI report (page 958) states:

In contrast to AR5, the solar Effective Radiative Forcing (ERF) in this assessment uses full solar cycles rather than solar minima. The pre-industrial TSI is defined as the mean from all complete solar cycles from the start of the 14C SATIRE-M proxy record in 6755 BCE to 1744 CE. The mean TSI from solar cycle 24 (2009–2019) is adopted as the assessment period for 2019. The best estimate solar ERF is assessed to be 0.01 W m⁻², using the 14C reconstruction from SATIRE-M, with a likely range of –0.06 to +0.08 W m⁻² (medium confidence). The uncertainty range is adopted from the evaluation of Lockwood and Ball (2020), who performed a Monte Carlo analysis of solar activity from the Maunder Minimum to 2019 using several datasets, resulting in an ERF range of –0.12 to +0.15 W m⁻². The Lockwood and Ball (2020) full uncertainty range is halved since the period of reduced solar activity in the Maunder Minimum had ended by 1750 (medium confidence).

By comparison, the AR5 WGI report (page 689) states:

The best estimate from our assessment of the most reliable TSI reconstruction gives a 7-year running mean radiative forcing (RF) between the minima of 1745 and 2008 of 0.05 W m⁻². Our assessment of the range of RF from TSI changes is 0.0 to 0.10 W m⁻².

Thus, the solar radiative forcing estimates in AR5 and AR6 are broadly consistent, with AR6's best estimate slightly lower, while its uncertainty including also negative values that AR5 did not. The authors of the DOE CWG report misused a different part from the AR6 WGI text to suggest that AR6 “shows a substantially greater solar impact than does AR5”, which is incorrect.

This claim arises due to AR6 WGI (page 297) listing a TSI difference between the Maunder Minimum and the second half of the 20th century ranging from 0.7 to 2.7 W/m². The 0.7 W/m² lower bound likely corresponds to the SATIRE-T reconstruction, while the upper bound comes from the Yeo et al. (2020) constraint on the dimmest possible solar state. It is important to note that Yeo et al. (2020) does not reconstruct TSI during the Maunder Minimum but rather provides a theoretical constraint on the minimum plausible solar irradiance. This constraint by Yeo et al. 2020 should not be interpreted as an actual historical TSI difference between the Maunder Minimum and the present, but rather as a physical upper bound on the maximum plausible difference between the Sun's dimmest possible state and its current irradiance. Importantly, the Maunder Minimum is unlikely to represent this dimmest state, and modern TSI reconstructions suggest a substantially smaller long-term trend than what a 2.7 W/m² Maunder-to-present difference would imply. This upper limit, derived from Yeo et al. (2020), effectively excludes high-variability TSI reconstructions that exceed this threshold, such as Egorova et al. (2018). Almost all current TSI reconstructions indicate significantly smaller long-term TSI trends (Chatzistergos et al. 2023). These include the SATIRE and NRL (now NNL) models recommended for CMIP6 and AR6.

8) ACRIM-gap

Page: 85

Comment type: Technical

Comment: The DOE report exaggerates the significance of the ACRIM-gap. The delay in the launch of ACRIM2 led to the necessity of using data from Nimbus7-ERB and ERBE-ERB. Nimbus7-ERB is the oldest TSI measuring instrument we have, while ERBE-ERB has lower quality and took observations more sporadically than Nimbus7-ERB. The whole ACRIM-gap issue originates in unaccounted sensitivity changes in either or both of those missions. Nimbus7-ERB suggested a slight increase in TSI between 1990-1992, while ERBE-ERB did not.

While a subset of literature has argued for decades that, through a certain interpretation of the ACRIM-gap, solar irradiance changes since 1978 are unknown or upwards, we have independently led two scientific studies that demonstrate a common understanding of the trends in solar irradiance since 1978, regardless of one's chosen interpretation of the ACRIM-gap.

First, Amdur and Huybers (2023), followed by Amdur and Huybers (2025), developed an independent statistical analysis using a sophisticated Bayesian approach inspired by the time series econometrics literature. In these studies, with clearly defined priors that make no *a priori* assumptions regarding the relative merits of using a given satellite or solar proxy in filling the ACRIM-gap, they find that the best estimate of Total Solar Irradiance (TSI) using almost all available observational satellite data supports a downward trend in TSI since 1978, in line with most reconstructions of irradiance.

Second, Chatzistergos et al. (2025) performed irradiance reconstruction with the physics-based semi-empirical model SATIRE-S using datasets that span the entire ACRIM-gap period and extend beyond it. This modeling approach returns long-term TSI trends that are independent of direct TSI measurements, although some uncertainty remains due to the quality of the input data. By applying the model separately to two independent datasets, Mt. Wilson magnetograms and reconstructed unsigned magnetograms from Meudon Ca II K observations, Chatzistergos et al. (2025) demonstrated that both reconstructions contradict the TSI increase suggested by some during the ACRIM-gap, providing independent evidence against that upward trend.

Thus, while the issues leading to the ACRIM-gap contribute to the uncertainty in the long-term trends in direct TSI measurements, both statistical and physics-based reconstructions relying upon independent data find a common resolution to the ACRIM-gap, and it is important to note that these findings are consistent with existing TSI composites that do not exhibit substantial disagreement (Kopp 2025). In particular, (Chatzistergos et al. 2023) in their Table 1 lists the trend between activity minima of cycle 25 (2019) and 22 (1986) and shows that it is rather small ranging between $-7.6 \text{ mW m}^{-2} \text{ y}^{-1}$ (Montillet et al. 2022) and $1.8 \text{ mW m}^{-2} \text{ y}^{-1}$ (Scafetta 2023) (the latter is an informal update of ACRIM TSI composite). Most recently, Amdur and Huybers (2025) found a trend of $-5 \text{ mW m}^{-2} \text{ y}^{-1}$ over this period.

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Response to section 8.3.3

Andreas Schmittner and Peter U. Clark, College of Earth, Ocean & Atmospheric Science, Oregon State University

This section is a **technical comment** on Section 8.3.3 of the DOE CWG report, beginning on **page 89**.

In the second paragraph the authors write “An application to the well-known Vostok ice core data revealed an error in Al Gore’s documentary *An Inconvenient Truth*. Gore showed the data and drew attention to the coherence of temperature and CO₂ changes over a 440,000 year span, which he asserted was due to CO₂ driving temperature changes. But temperature changes can also affect atmospheric CO₂ levels. Davidson et al. (2015) examined the series and found that temperature Granger causes CO₂ but not the reverse. In other words on the time scales represented in the Vostok data, the coherence in the series is primarily due to the influence of temperature on CO₂ levels, not the feedback of CO₂ levels on temperature.”

This section is contrary to the vast majority of paleoclimate literature, which has established that atmospheric CO₂ has an important influence on global temperatures during past ice-age cycles. For example, radiative forcing of CO₂ and ice sheets similarly contribute to colder temperatures during the Last Glacial Maximum (Broccoli, 2000; Broccoli & Manabe, 1987; Hansen et al., 1984; Köhler et al., 2010; Schmittner et al., 2011; Weaver et al., 1998) and simulations of glacial cycles with constant CO₂ underestimate ice volume changes (Abe-Ouchi et al., 2013; Ganopolski & Calov, 2011). This should be mentioned here, since otherwise it will leave the reader with the false impression that CO₂ variations are unimportant for ice age climate changes.

This section should also clarify that the Vostok ice core data are oxygen isotopes, a proxy for regional temperature in Antarctica. They do not represent global temperature. Using a reconstruction of global temperature over the last deglaciation (last 20,000 years) Shakun et al. (2012) find that CO₂ leads temperature and thus likely causes much of the warming over that time period. This should be mentioned here.

In the first paragraph there are several non-peer reviewed citations, e.g. Razzak (2021) and Dagsvik and Moen (2023). The Razzak (2021) paper is problematic because it removes the trends in both CO₂ and temperature data and then investigates the residuals, finding no correlations using only statistical methods. However, physical understanding of Earth’s radiation budget clearly suggests that the trend in CO₂ causes the observed temperature trend (Pierrehumbert, 2011). Thus, removing the trends in both time series is not appropriate for attribution studies. Razzak (2021) also ignores all other known influences on temperature such as internal variability (e.g. ENSO) and other external forcings such as aerosols. I suggest removing Razzak (2021) and other non-peer reviewed citations. Studies that include other forcings find convincing effects of CO₂ on global warming over the last 100 years (e.g. Lean and Rind, 2009).

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Technical Comment on the DOE CWG report, Section 8.4: Declining planetary albedo and recent record warmth

Robert Kopp, Rutgers University; Andrew E. Dessler, Texas A&M University

This is a **technical** comment on section 8.4 of the DOE CWG report (pp. 90–92), and its relation to section 4 of the DOE CWG report (pp. 25–30).

This section highlights the role of declining planetary albedo in recent record global warmth. Much of it summarizes Goessling et al. (2024) and Hansen and Karecha (2025).

Goessling et al. (2024) nicely states the conundrum this section addresses:

In 2023, the global mean temperature soared to almost 1.5 kelvin above the preindustrial level, surpassing the previous record by about 0.17 kelvin. Previous best-guess estimates of known drivers, including anthropogenic warming and the El Niño onset, fall short by about 0.2 kelvin in explaining the temperature rise. Using satellite and reanalysis data, we identified a record-low planetary albedo as the primary factor bridging this gap. The decline is apparently caused largely by a reduced low-cloud cover in the northern mid-latitudes and tropics, in continuation of a multiannual trend. Further exploring the low-cloud trend and understanding how much of it is due to internal variability, reduced aerosol concentrations, or a possibly emerging low-cloud feedback will be crucial for assessing the present and expected future warming.

As the quote indicates, this is actually a small mystery — out of $\sim 1.5^{\circ}\text{C}$ of warming, about $\sim 0.2^{\circ}\text{C}$ is unexplained. One could reasonably look at this as an indication of how successful climate science is that we find such small differences notable.

When considering the importance of events like this, it's useful to remember that the climate system is always doing unusual things. For example, in the 2000s, climate skeptics were laser focused on the so-called “hiatus”, a supposed lack of warming in the surface temperature record between the late 1990s and early 2010s. Some people claimed this falsified mainstream climate science.

But, as climate scientists always said would happen, the warming returned with a vengeance in the mid-2010s. In hindsight, the hiatus was simply unusual climate variability, likely connected to ocean dynamics (e.g., Kosaka and Xie, 2013), and its occurrence has no serious implications for long-term climate change (England et al, 2015).

What we've experienced in the last two years has also been equally extraordinary although in the other direction. As a result, scientists have worked hard to explain the warming. Potential explanations include:

Aerosols: Aerosols cool the climate by reflecting sunlight back to space. As humans work to reduce air pollution, this cooling mask is being removed, adding additional heat to the climate system. However, estimates of radiative forcing due to reduction in aerosols suggests that this was too small to produce the observed 2023-2024 excess warming (e.g., Gettelman et al., 2024).

Hunga Tonga volcanic eruption: The eruption of the Hunga Tonga volcano in early 2022 dramatically perturbed our atmosphere by injecting enormous amounts of water vapor directly into the stratosphere. However, estimates of radiative forcing show it was too small to be a factor in the 2023-2024 heat (Schoeberl et al., 2022). In fact, we don't even know if the eruption warmed or cooled the climate.

Natural variability + cloud feedback: Recent work (England et al., 2025) has suggested an intriguing possibility: unusually low wind speeds caused the surface ocean mixed layer in the North Atlantic to become very shallow. Because the mixed layer was thin, it warmed rapidly. When combined with the weak winds, the very warm ocean reduced cloud cover. And with fewer clouds, more sunlight reached the ocean surface, further amplifying the warming. While the immediate trigger was low winds due to unforced variability, climate change has been driving a long-term trend toward shallower mixed layers, making extreme events like this more likely.

The DOE CWG report concludes:

While it is difficult to untangle causes of the recent trend, the competing explanations for the cause of the declining cloud cover have substantial implications for assessing the Equilibrium Climate Sensitivity and for the attribution of the recent warming. An additional 10 years of data should help clarify whether this is a strong positive cloud feedback associated with warming or a temporary fluctuation driven by natural variability. (p. 92)

It is not clear what point the DOE CWG report is trying to make here. If, as they suggest, the albedo decline represents a strong positive climate feedback, then it means that “the lower end of realistic climate sensitivity estimates of 2.3 to 4.7 K may need to be adjusted upward” (Goessling et al., 2024) — meaning that warming will be at the upper end of the model-projected range. Hansen and Karecha (2025), cited by the DOE CWG report, argue for a climate sensitivity of $4.5^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$ (1σ).

If the albedo decline does not indicate a strong positive cloud feedback, then the existing ECS range of $2.5\text{--}4^{\circ}\text{C}$ would remain appropriate. Notably, the report presents no evidence or even an argument suggesting that this event means that the mainstream ECS range might be too high.

This creates a significant inconsistency within the report. The discussion of climate sensitivity in Chapter 4 (pp. 25-35) does not engage with the active research area described in Section 8.4, instead concluding that "Data-driven ECS estimates tend to be lower than climate model-generated values" (p. 25) — a conclusion that appears inconsistent with the albedo evidence presented elsewhere.

The DOE CWG report should be revised to ensure its discussion of Equilibrium Climate Sensitivity in Chapter 4 reflects the emerging science on declining planetary albedo and potential strong positive cloud feedback discussed in Section 8.4.

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Response to Section 8.5. Attribution of Climate Impact-Drivers

Andrew King, University of Melbourne and Andrew E. Dessler, Texas A&M University

Section 8.5 (pp. 92-94) of the DOE CWG report outlines their perspective on the attribution to anthropogenic forcings of Climate Impact-Drivers (CIDs). This section includes several misunderstandings of what CIDs represent and what is shown in IPCC Table 12.12 as highlighted below.

Comment: Technical

The DOE report pretends that this table is where the IPCC establishes the attributed signal of climate change. For example, they say that this table shows that “few CIDs exhibit an anthropogenic signal sufficient to distinguish them from natural variability.”

In fact, those tests were performed in attribution studies assessed elsewhere in the report. For example, chapter 11 describes how the anthropogenic signal is detected and attributed in extreme heat (Section 11.3.4), heavy precip (Section 11.4.4), etc, and earlier chapters look at water, energy, land, ocean, biosphere and cryosphere detection and attribution. There is also a prominent section on detection and attribution in chapter 11 (Fig 11.4 and accompanying text).

Table 12.12 is a specific assessment of emergence across broad regions that goes far beyond a detection of climate change or attribution to human influence (which is well described in the IPCC’s Chapter 11). Table 12.12 looks specifically at whether the average year now exceeds the historical range of variation (this is what is meant by “emergence”). For example, is the average annual temperature now warmer than the warmest year in the historical period (which would have been affected by natural variability like ENSO cycles).

Simple physical reasoning tells us that fully emerging from the noise of the historical record happens more rapidly for mean conditions than extremes, so you can see in the table that the mean conditions surpass this “emergence” criterion first with extremes increasingly emerging in the coming decades.

For further context, we reproduce below (Figure 1) a LinkedIn post made by one of the coordinating lead authors of chapter 12 that verifies what the author team was thinking in Table 12.12.

Suggested action:

- Fix the errors in this discussion arising from the DOE CWG not understanding what a CID actually is.

Comment: Technical

The DOE CWG report’s Table 8.1 (Page 94) is intended to be a partial reproduction of Table 12.12 of the IPCC Sixth Assessment Report Working Group 1. With the original table, the IPCC authors are seeking to synthesise available studies on CIDs and where there is a body of evidence to support detectable anthropogenic CIDs, this is noted. The IPCC text notes

that a lack of literature inhibits confidence in robust detection in many cases (e.g. “Studies are missing to properly assess S/N emergence for droughts and for wind CIDs.” P. 1855) and takes the approach that only when there is sufficient evidence in the peer-reviewed literature, a detectable signal of emergence is noted. Such CIDs without sufficient evidence are displayed as white cells.

The DOE CWG report misrepresents these white cells to mean “no signal detected” — suggesting that evidence exists of no signal. This substantially changes the interpretation of the Table. The IPCC report explicitly acknowledges there is a lack of peer-reviewed studies on all CIDs of interest so not every white cell means no signal has been detected, it can also mean that there is a lack of relevant analysis in the literature. This misinterpretation in the DOE CWG gives the false impression that analysis of CIDs has failed to identify signals whereas in some cases there is actually no analysis.

This misinterpretation extends to the text in the DOE CWG report. On page 93 the DOE CWG report states “Nonetheless a striking feature of that summary table is how few CIDs exhibit an anthropogenic signal sufficient to distinguish them from natural variability,” thereby indicating that a white cell represents a lack of anthropogenic signal and excludes the case of a lack of comprehensive peer-reviewed literature.

Suggested action:

- Edit the Table 8.1 caption to match the IPCC’s text in describing how white cells should be interpreted.
- Discuss the challenge of a lack of peer-reviewed literature in some aspects of Climate Impact-Drivers the IPCC seeks to cover and edit the text accordingly.

Comment: Technical

Page 93 includes the line “Note that one of the CIDs is an increase in CO₂ levels, and since it is a tautology to attribute this to increased CO₂ levels this CID can be ignored.” This misconstrues what a CID is and even misrepresents the definition given a few lines earlier on p. 92 of the DOE CWG report that states: “CIDs are those features of the weather and climate system of primary interest in assessing the impacts of climate change since they potentially affect humans and the natural world”. Given the proven very large role of increased atmospheric carbon dioxide levels on the global mean temperature and many other aspects of the climate system, it would certainly meet the definition of a CID.

Suggested action: Remove the line suggesting that increase in CO₂ levels does not constitute a CID.

Comment: Technical

Page 93 includes the following lines “Of the five high confidence assertions, two are for changes in average temperatures (air and ocean) hence are not measures of extreme weather. Further, two of the four medium confidence assertions are related to ocean chemistry and thus are likewise not related to extreme weather. The IPCC does not assert a human influence on many non-temperature weather features such as wind, precipitation, flooding, or drought.”

These statements confirm the misunderstanding of what constitutes a Climate Impact-Driver (CID). As discussed above, CID are not just trends.

This section also repeats the misunderstanding what the white cells in the table represent. In many cases, the lack of emergence of anthropogenic influence in many CIDs is due to a lack of studies rather than a lack of a signal. As noted previously, the IPCC report states on p. 1855 “Studies are missing to properly assess S/N emergence for droughts and for wind CIDs.”

Suggested action:

- Edit the text to reflect that CIDs are not isolated to climate extremes.
- Acknowledge that a lack of peer-reviewed literature challenges the robust detection of anthropogenic signals in the emergence of climate changes.

Comment: Technical

There follows a discussion of issues with RCP8.5. This follows other text on this scenario on Pages 15 and 16 in the DOE CWG report. A response to section 3.2 has also been provided.

Suggested action: Edit this section to reflect the comments raised in response to section 3.2.

Comment: Technical

Page 93 of the DOE CWG report goes on to state “As discussed in Chapter 6 natural variability dominates patterns of extreme weather systems and simplistic assertions of trend detection are frequently undermined by regional heterogeneity and trend reversals over time. Table 8.1 makes the related point that it is not currently possible to attribute changes in most extreme weather types to human influences. Taking wind as an example, the IPCC claims that an anthropogenic signal has not emerged in average wind speeds, severe windstorms, tropical cyclones or sand and dust storms, nor is one expected to emerge this century even under an extreme emissions scenario. The same applies to drought and fire weather.”

Again, this confuses CIDs with simple trends. There are many places in the IPCC report (e.g., chapter 11) where trends in various quantities have been identified, although there might not be a trend in a CID.

Suggested action: Edit this section to better reflect the definition of a CID and clearly acknowledge that the white cells in Table 8.1 (12.12 in the IPCC AR6 WG1 report) refer to a lack of available literature as well as a lack of detectable signal.

Robert Vautard · 3rd+
IPCC WG1 co-chair - Senior Climate Scientis...
2w · 🌐

+ Follow ...

My IPCC journal - Reacting to a classical misinterpretation of the "emergence" of Climatic Impact-Drivers trends, as assessed in IPCC AR6 WGI Table 12.12. This Table has been used in several occasions to downplay the current influence of human activities on extreme events, while this influence is established in many regions for several types of extreme events (see AR6 WGI Chapters 11 and the SPM), and for other climatic impact drivers (see Table TS.5 of the Technical Summary, of which an example is found in the visual).

⚡ "Emergence" is a strong magnitude condition for a change, and is a different concept from "detection and attribution of human activities". In Table 12.12, emergence is used for changes larger than one standard deviation of the observed index. This means a STRONG shift of the distribution of the index. Many changes are less than one standard deviation in magnitude so far, despite having detectable human influence and inducing significant impacts, such as for heat extremes. The precise definition of all these concepts is given in the IPCC Glossary.

👉 <https://lnkd.in/e53vzd5p>

The misinterpretation has been made in the recently published U.S. DoE Report on (see ref. below), which concludes from the emergence table that "The IPCC does not assert a human influence on many non-temperature weather features such as wind, precipitation, flooding, or drought" 🌧️ ☀️. This is not what this table says, as it does not assess detection and attribution of human activities 🧑🏫 in weather features.

Report: <https://lnkd.in/eRP-ksHE>

⚡ Furthermore, as explained clearly in AR6 WGI Chapter 12, the lack of confidence in "emergence" of many of the changes does not necessarily mean that there is no emergence, it can also mean a lack of data or studies. This is well explained in the AR6 WGI Table 12.12 legend.

Finally, it is a misinterpretation of Chapter 12 that "One of the themes of this chapter is that attribution methods used by the IPCC tend to overstate the anthropogenic influence and understate the role of natural variability." Attribution is assessed in Chapter 11, not in 12. Table 12.12 is about magnitude of changes, not attribution of anthropogenic influence.

The table 📄 in the visual shows the changes across the list of climatic impact-drivers (CIDs) in North America and Europe, as an example. It is extracted from the AR6 WGI Technical Summary, for the regions of North America and Europe. Colors refer to confidence in projected future changes for a ~2°C global warming, but already detectable changes are marked with an arrow, and with ** or *** when enough studies allowed to establish a causal link with human influence. In particular, attributable changes can be seen for heat/cold extremes, heavy precipitation, droughts, in several regions.

Table TS.5 (continued)

	Heat and Cold	Wet and Dry	Wind	Storm and Ice	Coastal and Oceanic	Other
	Heat extremes (days above 35°C)	Wet extremes (days above 95th percentile)	Wind extremes (days above 95th percentile)	Storm extremes (days above 95th percentile)	Coastal extremes (days above 95th percentile)	Other extremes (days above 95th percentile)
Europe						
Mediterranean	***	**	**	**	**	**
Western and Central Europe	***	**	**	**	**	**
Eastern Europe	***	**	**	**	**	**
Northern Europe	***	**	**	**	**	**
North America						
North America	***	**	**	**	**	**
Central North America	***	**	**	**	**	**
Eastern North America	***	**	**	**	**	**
North America	***	**	**	**	**	**
North America	***	**	**	**	**	**
North America	***	**	**	**	**	**

Note: There are several region-specific qualifications attached to some of the directions of change/likelihood levels indicated above. (12.14)

Key for observational trend evidence: *** high confidence for more; ** medium confidence; * low confidence; - low confidence of decrease; - medium confidence of decrease; - high confidence of decrease; - not likely to occur.

Key for attribution evidence: *** high confidence for more; ** medium confidence; * low confidence; - low confidence of decrease; - medium confidence of decrease; - high confidence of decrease; - not likely to occur.

Figure 1. LinkedIn [post](https://lnkd.in/e53vzd5p) from IPCC chapter 12 coordinating lead author Robert Vautard discussing how the DOE CWG report does not interpret climate impact-drivers correctly.

Section 8.6 Extreme event attribution (EEA)

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Synopsis

This section of the DOE CWG report, on pages 95-96, attempts to assess the evidence for the anthropogenic influence on extreme weather and climate events through the lens of extreme event attribution. It first misrepresents the findings of the IPCC. It then focuses on the work of a single group (World Weather Attribution) using only one type of EEA method, neglecting the rest of the field. It provides almost no citations to relevant peer-reviewed literature in the field of EEA.

To correct these issues, the DOE CWG report needs to:

- Accurately assess the field of EEA, which constitutes hundreds of peer-reviewed studies using a range of different methods, all with different benefits and limitations. This requires accurately citing relevant peer-reviewed scientific literature.
- Provide citations to relevant peer-reviewed scientific literature when critiquing methods, both to describe those methods clearly and to support relevant criticisms
- Accurately reflect the underlying question of EEA, which does not claim or seek to show that anthropogenic warming ‘causes’ any given event, but that it may influence the properties (likelihood, magnitude, duration) of any given event or class of events.

More detailed comments are provided below. In several cases, comments are of the form ‘Technical/Reference’, where both technical flaws are found and the relevant literature is either missing or is misinterpreted.

Detailed Assessment of Report Conclusions

Comment 1

Page: 95

Comment type: Technical/Reference

Comment:

The DOE CWG Report attempts to contrast the conclusions of Chapters 11 and 12 of the IPCC AR6 Working Group 1 (WG1) report, claiming that the report as a whole provides an “ambiguous assessment of the role of anthropogenic warming” [page 95]. This argument is a misleading interpretation of the IPCC report. The conclusions for these two chapters are consistent because they address different questions. To make this misleading comparison, the authors of the DOE CWG Report make inaccurate statements on the results from Chapter 12. These comments are explained below.

The climatic-impact driver (CID) analysis in WG1 Chapter 12 focuses on the *emergence* of a climate change signal, in either means or extremes (Ranasinghe et al., 2021). An emergence of a climate change signal “occurs when that signal exceeds some critical threshold (usually taken to be a measure of natural variability; see for example Hawkins and Sutton, 2012) or when the probability distribution of an indicator becomes significantly different to that over a reference period (e.g., Chadwick et al., 2019)” (Section 12.5.2, Ranasinghe et al., 2021). In Table 12.12 specifically, emergence refers to changes larger than one standard deviation of the observed index. It does not assess detection and attribution of anthropogenic forcing in extreme weather occurrence. This is also discussed in the response to Section 8.5 by King and Dessler.

WG1 Chapter 11 instead focuses on *trend and event attribution* of extreme weather and climate events (Seneviratne et al., 2021). Trend attribution, documented by the IPCC since AR4 (Hegerl et al., 2007), explains the causes of long-term trends in mean climate conditions, and also in certain extreme weather or climate indices. Aggregating across regions helps to identify changes that are influenced by global scale drivers such as greenhouse gas increases and allows careful separation of the influence from different drivers such as solar forcing and aerosols. Many changes have detectable human influences, but are less than one standard deviation in magnitude so far. The authors of the DOE CWG report can refer to the IPCC Glossary for definitions of each concept (<https://apps.ipcc.ch/glossary/>).

A further issue arises in the interpretation of Table 12.12. Here, confidence in emergence is conflated with data availability, meaning that a white cell (“low confidence in direction of change”) could indicate either that there is no emergence, or that there is a lack of data or studies (Table 12.12 caption, Ranasinghe et al., 2021; see comments on section 8.5 of this report).

Comment 2

Page: 95

Comment type: Technical

Comment:

This section of the DOE CWG report focuses solely on the work of World Weather Attribution (WWA). This is a significant misrepresentation of the field of extreme event attribution (EEA). WWA primarily uses probabilistic event attribution, which is only one of several EEA methods, and is only one of many groups that perform EEA studies. Beyond probabilistic attribution, there are many other groups and institutions using and developing different EEA methods, which are not discussed in this report at all. These methods include, but are not limited to, forecast-based attribution (e.g. Leach et al., 2024; Ermis et al., 2024; Reed et al., 2020), spectrally nudged storylines (e.g. Sanchez-Benitez et al., 2022; Klimiuk et al., 2025), and pseudo-global warming (e.g. Lenderink et al., 2025; de Vries et al., 2024). This omission greatly limits the scope of this report in its review of EEA.

In addition, the description of the probabilistic WWA approach is also misleading and implies that it uses a single line of evidence (regional climate models) rather than a well-established and peer-reviewed method combining multiple lines of evidence (Philip et al., 2020a, van Oldenborgh et al., 2021). The WWA approach uses multiple sources of observational and reanalysis data, as well as a combination of global and regional climate models relevant to the event of interest. Furthermore, in the case of complex or multivariate events, multiple methods may be used to provide additional insight (e.g. Barnes et al., 2025; Clarke et al., 2024). Other organizations conduct EEA analyses using this approach, including several national meteorological services, such as the Australian Bureau of Meteorology (e.g. Hope et al., 2024), the Royal Netherlands Meteorological Institute (e.g. Philip et al., 2022; Philip et al., 2020b), the UK Met Office (e.g. Christidis et al., 2023), the German meteorological service (e.g. Schröter et al., 2024), the Japan Meteorological Agency (e.g. Kawase et al., 2022), and the Meteorological Service of Canada (e.g. Gillett et al., 2022).

Comment 3

Page: 95

Comment type: Technical/Reference

Comment:

The DOE CWG report claims that “WWA’s extensive promotion of non-peer-reviewed findings, its open admission to shaping analyses to serve litigation, and its methodological challenges have sparked controversies, with critics questioning the robustness and impartiality of their conclusions (Pielke Jr. 2024)”.

WWA studies use rigorous peer-reviewed methods (Philip et al., 2020a, van Oldenborgh et al., 2021; Ciavarella et al., 2021; Otto et al., 2024). Furthermore, many studies have been peer-reviewed in the aftermath of the initial rapid study (e.g. van Oldenborgh et al. 2017; Zachariah et al., 2022; Kimutai et al., 2025). To date, 26 such studies have been peer-reviewed,

with no significant change to the results or conclusions. In making this point, the DOE CWG report implies that the peer review process is important, especially for a document used to inform government policy. The scientific community agrees strongly with this sentiment.

The claim that WWA has an “open admission to shaping analyses to serve litigation” is unfounded and false. The purpose of WWA as set out publicly on its website (<https://www.worldweatherattribution.org/about/>, accessed 08/07/2025) is as follows:

*“Working with scientists around the world, WWA quantifies how climate change influences the **intensity** and **likelihood** of an extreme weather event in the immediate aftermath of the extreme event using weather observations and computer modelling. To encourage actions that will make communities and countries more resilient to future extreme weather events, WWA studies also evaluate how existing vulnerability worsened the impacts of the extreme weather event. The results are made public as soon as they are available, often days or weeks after the event, to inform discussions about climate change and extreme weather.”*

Finally, the “controversies” and “critics” all refer to a single reference of a blog article by a single author “(Pielke Jr. 2024)”, rather than robust peer-reviewed scientific literature. There are also no citations to the abundant peer-reviewed EEA literature itself in making these claims.

Comment 4

Page: 95

Comment type: Technical/Reference

Comment:

In reference to the WWA method, the DOE CWG report further claims that “Technical criticisms of the approach include a lack of a formal detection process; an implicit assumption that 100 percent of the post-industrial warming is caused by greenhouse gases; and a failure to adequately account for internal climate variability.” Given the lack of citations behind these claims, they are simply taken exactly as written.

First, it is unclear what is meant by the “lack of a formal detection process”, and as discussed above, the process is detailed and published with peer-reviewed papers published in scientific journals linked to the WWA website.

Second, on the “implicit assumption that 100 percent of the post-industrial warming is driven by greenhouse gases,” IPCC WG1 Chapter 3 concluded that approximately 100% of global surface temperature change from 1850-1900 to 2010-2019 was anthropogenically driven (Eyring et al., 2021), and the DOE CWG report does not provide evidence against this conclusion. Furthermore, model analysis does not assume 100% of warming is anthropogenically driven; instead, comparing the historical and early parts of future simulations with naturally forced or pre-industrial control simulations makes no underlying assumption about the cause of warming.

Third, a “failure to adequately account for internal climate variability” is unclear, because “adequately” is not a scientifically defined term. This is compounded by the lack of supporting

citation. However, this is also an outdated criticism more broadly. The peer-reviewed WWA method has been updated (also via peer review) to account for internal climate variability, by including relevant mechanisms (such as the El Nino Southern Oscillation or Indian Ocean Dipole) as additional covariates in the statistical modelling. These are included in any EEA study in which these factors are known to influence extremes in the region (e.g. Kimutai et al., 2025).

Comment 5

Page: 95

Comment type: Technical/Reference

Comment:

The DOE CWG report raises the challenge of the “lack of data” for EEA. There are a range of established methods for dealing with this issue. In the case of probabilistic attribution, which the report focuses on solely, the main approach is to use many data sources.

First, several observational and reanalysis datasets exist for EEA analysis. These do often begin in 1950 (e.g. ERA5; Hersbach et al., 2020) or in the 1970/80s, but may go back to 1920 or earlier (such as E-OBS; Cornes et al., 2018, and CRU TS; Harris et al., 2020), depending on the geographical region and temporal resolution. As the authors identified in previous sections (e.g. section 6.4, p. 61), weather station records often go back more than a century, and the very longest composite records go back even further. For instance, the central England temperature record stretches back to the 1600s (Legg et al. 2024).

The second source of data is climate models, which is not mentioned in the DOE CWG report. This includes but is not limited to global and regional climate models. By using many such models, each of which contributes approximately a century of data, any given probabilistic attribution study draws on several hundred to several thousand years of data. This is a basic, foundational and widely understood aspect of probabilistic event attribution, backed by peer-reviewed literature.

More broadly, the report claims that the aim of EEA is only to identify and study events that are beyond “thresholds of what is expected from natural variability”. On the contrary, it is very often the case that a dangerous extreme weather event would have been possible with or without the influence of human induced climate change. However, the likelihood of an event exceeding a given magnitude (or, equivalently, the magnitude of an event of a given likelihood) may have changed because of human induced climate change.

Comment 6

Page: 96

Comment type: Technical

Comment:

This section of the DOE CWG report also highlights that assessing changes in different extreme atmospheric events with similar meteorological impact variables is a challenge. However, as in the rest of the section, it oversimplifies the approaches taken in probabilistic attribution studies to address this challenge. In these studies, the degree to which the statistical model fits the data is then investigated. This enables a judgment over whether the extremes in question can be well represented by a single distribution to enable an EEA study. The climate models used are also assessed for their ability to represent such extremes.

More importantly, the DOE CWG report neglects all other EEA methods. Almost all other EEA methods are more highly ‘conditioned’ than the probabilistic approach. This means that they begin the attribution analysis by conditioning on the atmospheric state, or circulation “regime”, such as the inland blocking event resulting in a heatwave as described in the DOE CWG report (Shepherd, 2016; Trenberth et al., 2015). The weather event resulting from this unusual atmospheric state can then be perturbed using well understood thermodynamic influences of climate change, such as observed and projected changes in sea surface temperatures. The exact details vary by method (see comment on the range of EEA methods and references therein), but broadly this enables an assessment of how such an event in the same “regime” unfolds in warmer and cooler climates. This challenge has been well understood and addressed by the EEA community for nearly a decade. The lack of references to any of this large body of work again illustrates the significantly limited scope of the DOE CWG report.

Comment 7

Page: 96

Comment type: Technical/Reference

Comment:

The report has misinterpreted the overarching message of the literature on EEA. On page 96, the DOE report states “Visser and Petersen argue that, in view of the deep uncertainties of extreme weather analysis, drawing a connection between individual events and global climate change should be avoided.” However, Visser and Petersen (2012) explicitly agree with a previous study (Schär and Jendritzky 2004) who stated the following: “The European heatwave of 2003: was it merely a rare meteorological event or a first glimpse of climate change to come? Probably both.”, as well as with Stott et al. (2004), a foundational paper of EEA, which states: “It is an ill-posed question whether the 2003 heatwave was caused, in a simple deterministic sense, by a modification of the external influence on climate – for example, increasing concentration of greenhouse gases in the atmosphere – because almost any such weather event might have occurred by chance in an unmodified climate.”

This reflects the wider view of the attribution community: no extreme weather events are caused by climate change but all extreme weather events may be influenced by it. This was firmly established in the EEA literature in 2012, when two apparently contradictory studies were reconciled by Otto et al. (2012), who showed that an event could both be caused predominantly by natural variability and influenced by climate change. In conclusion, the literature does not support the claim in the DOE CWG report that “drawing a connection between individual events

and global climate change should be avoided”. This point is developed in the following case study.

Section 8.6.1: Case study – 2021 Western North America heat wave

This section of the DOE CWG report, on pages 96-97, summarizes the evidence on anthropogenic influence on the June 2021 Pacific Northwest (PNW) extreme heat event. They use this event as a “case study” to “illustrate the challenges and ambiguities in attributing the frequency and intensity of extreme weather events to human-caused warming.” As detailed below, the DOE CWG report accurately summarizes the meteorological conditions that contributed to the heat event. However, they reach misleading conclusions regarding the overall human influence on this event.

To correct these issues, the DOE CWG report needs to:

- Distinguish between meteorological drivers of extreme events and the thermodynamic intensification of those events due to climate change.
- Accurately reflect the consensus of studies regarding the role of warming in producing warmer surface temperatures during the 2021 PNW heat wave.

Comment: Editorial

The DOE CWG report contrasts the WWA attribution study of this event with “subsequent peer-reviewed analyses” showing that this heat wave “was caused by rare meteorological conditions that were not made more probable by global warming” (p. 97).

This statement is misleading. Extreme weather events in a warming world occur due to the *combination* of anomalous meteorological conditions *and* the influence of climate change (Trenberth et al., 2015). In the case of the PNW, the meteorological conditions were indeed extreme, resulting in a surface heat wave that would have been high-impact regardless of the background climate. However, the scientific evidence is clear that global warming thermodynamically increased the temperature of the PNW heat wave, even if it did not affect the intensity of the high-pressure system or other meteorological precursors. This idea is reflected in numerous peer-reviewed studies of this event:

- McKinnon and Simpson (2022) state that “The meteorological causal factors for the heatwave occurred on top of a changing mean state due to human influence on the climate system.”
- Bercos-Hickey et al. (2022) conclude that “there is little doubt that anthropogenic global warming contributed to the probability and magnitude of the extreme temperatures.”
- Bartusek et al. (2022) find that “even gradual warming over recent decades has dramatically transformed the character of this extreme heat event,” and that “[c]ontinued warming will cause the probability of an equal or stronger event to rapidly increase.”

Comment: Reference

While the DOE CWG report cites many relevant and high-quality references in this section, they appear to **cherry-pick sentences to downplay the influence of climate change on the event.**

For example, the report cites the 2023 Oregon Climate Assessment (Fleishman, 2023) to state that climate change did not make the “heat dome” more likely. Yet the report neglects the explicit statement of the Oregon Climate Assessment that “[a] heat dome would have occurred without climate change, but **maximum temperatures would not have been as high**”.

Additionally, the DOE CWG report cite McKinnon and Simpson (2022) to state that the event was “bad luck,” but ignore the paper’s statements that “[c]hanges in the mean state alone will increase the probability, intensity, and duration of heat waves (Meehl & Tebaldi, 2004); this shift is a well-understood consequence of climate change,” and that “climate change added additional warming to the picture.” Indeed, the citation of McKinnon and Simpson (2022) illustrates why care is needed in faithfully representing the work of scientists in this area: this paper is particularly interested in understanding “whether the probability of very extreme events is changing *faster than would be predicted by a change in the mean*” (emphasis added). Therefore, they *remove* the forced signal of climate change from their climate model simulations before analyzing the probability of the PNW heat wave. The language of “bad luck” therefore refers to the occurrence of very extreme temperatures on top of a mean shift linked to climate change. This nuance is not considered in the DOE CWG report, which appears more concerned with cherry-picking particular phrases that allow them to dismiss the role of climate change.

Comment: Editorial

Much of this section of the DOE report is concerned with the difficulties of confidently estimating the probability of very extreme events, given that they are by nature very rare (p. 97). This statement is correct, but **several methodological developments not discussed by the report enable more confident attribution of extremely rare events**. Zhang et al. (2024) leverage the spatial dependence of weather stations in the PNW, enabling them to better represent the PNW event in extreme value statistics and leading to the conclusion that “anthropogenic GHG emissions increased the likelihood of observed extreme temperatures in 2021.” Alternative approaches include “storyline” attribution, where a regional climate model is run under both a realistic scenario and a “counterfactual” scenario without global warming. This approach does not require estimating uncertain extreme value distributions, and allowed Bercos-Hickey et al. (2022) to conclude that “the anthropogenic temperature increase is about 1 °C.”

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Response to Department of Energy Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate, July 2025 - Chapter 9: Climate Change and US Agriculture

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Below are technical comments to statements made within Chapter 9 of the DOE CWG Report. The page numbers associated with each statement/comment grouping indicates the page on which the statement starts.

Overview of Comments on this Chapter

Page 104-108

Comment Type: Technical

This chapter presents an incomplete and misleading picture of the relationship between rising atmospheric CO₂ and agricultural productivity. It focuses narrowly on the direct fertilization effect of CO₂—its potential to boost crop yields under ideal conditions—while largely ignoring the broader and well-documented negative impacts of CO₂-driven climate change on crop yields. The scientific consensus is that CO₂-induced climate change, including rising temperatures, shifting weather patterns, and altered precipitation, will outweigh the benefits of CO₂ fertilization, leading to net yield declines across major agricultural regions in the U.S. and globally (Auffhammer & Schlenker, 2014; Hsiao et al., 2019; Hultgren et al., 2025; Jägermeyr et al., 2021; Lobell et al., 2011; Lobell & Field, 2007; Muehe et al., 2019; Zhu et al., 2023).

The chapter acknowledges that elevated CO₂ levels can dilute the nutrient content of crops, but downplays the significance of this issue for human health by overstating the potential of biofortification and dietary supplementation to fully offset nutrient deficiencies. The chapter fails to acknowledge a growing body of literature that links CO₂-induced climate change, including rising temperatures, to increased concentrations of toxins in crops.

ACTION: The chapter needs to accurately reflect the full scope of what is known about the impacts of CO₂ and CO₂-induced climate change on agriculture, including the likelihood of yield reductions and food quality risks, rather than focusing narrowly on CO₂ fertilization effects

Chapter summary

Page 104

Comment Type: Technical

DOE CWG STATEMENT: *“There has been abundant evidence going back decades ... that CO₂-induced warming will be a net benefit to U.S. agriculture.”*

COMMENT: The DOE report provides little evidence that CO₂-induced warming will be a net benefit to U.S. agriculture and ignores a vast literature which reaches the opposite conclusion. The only section in which temperature is discussed as having a potentially positive impact on agriculture is Section 9.1. (Note: Section 9.3 incorrectly claims that Figure 9.2 shows a yield increase with temperature; see response to section 9.3 below). Section 9.1 reviews economic studies that use historic data to connect climate variations with agricultural land values under the assumption that “if climate change is a long-term net benefit for agriculture it should be capitalized into higher market values for agricultural land.” The reviewed studies had a range of outcomes. Three found warming led to declines that were statistically significant, one found warming had no perceivable impact, two found warming led to a slight benefit, and one study found warming led to a large benefit for French agriculture, which is not expected to be relevant to the U.S. context. This range in responses is far from supporting the statement that warming will be a net benefit to U.S. agriculture.

Indeed, DOE CWG Section 9.1 completely ignores a vast literature spanning methodological approaches that reaches precisely the opposite conclusion, finding large and robust agricultural losses from CO₂-induced warming both for the U.S. and for the globe, several of which already account for gains from CO₂ fertilization (Auffhammer & Schlenker, 2014; Hsiao et al., 2019; Hu et al., 2024; Hultgren et al., 2025; Jägermeyr et al., 2021; Lobell et al., 2011; Lobell & Field, 2007; Su et al., 2023; Zhao et al., 2017). Further, physiological studies of crops show there is an optimal temperature at which yields maximize. When temperatures are below or above this optimal point, yields decline (Djanaguiraman et al., 2020; Khan et al., 2021; Neild & Newman, 1990; Su et al., 2023). Therefore, positive historic responses to temperature could reflect plants reaching their optimal growing conditions. Pushing temperature beyond this point will not result in a continued increase, but rather a yield decrease.

ACTION: The authors need to remove the statement that there has been abundant evidence going back decades that CO₂-induced warming will be a net benefit to U.S. agriculture. This statement is unsupported and does not align with current understanding.

Page 104

Comment Type: Technical

DOE CWG STATEMENT: *“There is reason to conclude that on balance climate change has been and will continue to be neutral or beneficial for most U.S. agriculture.”*

COMMENT: Again, DOE CWG Chapter 9 completely ignores a vast literature spanning methodological approaches that finds large and robust agricultural losses from climate change both for the U.S. and for the globe, several of which already account for gains from CO₂ fertilization (Auffhammer & Schlenker, 2014; Hsiao et al., 2019; Hu et al., 2024; Hultgren et al., 2025; Jägermeyr et al., 2021; Lobell et al., 2011; Lobell & Field, 2007; Su et al., 2023; Zhao et al., 2017). The overwhelming balance of the literature directly contradicts this statement in the DOE CWG Report.

ACTION: The authors need to remove the statement that “on balance climate change... will continue to be neutral or beneficial for most U.S. agriculture” and replace it with a summary that actually reflects the broad literature on this issue – namely that it is expected that CO₂-induced climate change will lead to agricultural losses.

9.1 Econometric analyses

Page 104

Comment Type: Technical

DOE CWG STATEMENT: *“Mendelsohn et al. (1994) examined the relationship between historical climatic variations on agricultural land values and concluded global warming would be slightly beneficial to American agriculture. The Mendelsohn et al. method, called Ricardian analysis after David Ricardo, the 19th century British economist who pioneered the study of land values, attracted subsequent criticism from authors who argued it failed to account for differences in land values attributable to fixed locational characteristics like soil quality, and non-climatic changes including nearby urbanization.”*

COMMENT: This report’s reliance on the Mendelsohn et al (1994) findings (hereafter “MNS”) is a misleading summary of the state of the literature. MNS – published over 30 years ago – employs a cross sectional regression estimator that is now widely recognized as vulnerable to confounding, or “omitted variables bias” as it is termed in the econometrics literature broadly (Angrist & Pischke, 2009, Chapter 3; Wooldridge, 2010, Chapter 4). This is a fundamental problem with the empirical approach employed by MNS and is also widely recognized in the literature on climate change and agriculture (see for example reviews Auffhammer & Schlenker, 2014; Hsiang, 2016). In particular, work following MNS showed that the MNS estimator omitted irrigation, confounding profits in warmer U.S. climates with the irrigation systems present in those climates (Schlenker et al., 2005). Once they accounted for this issue, Schlenker et al. (2005) found losses to farm land values in the Central and Eastern U.S. under future warming.

ACTION: This report should include a discussion of the methodological shortcomings in MNS, including discussion of more recent follow-on work in Schlenker et al 2005 and its critique of the MNS cross sectional hedonic approach. The critique of the cross-sectional hedonic approach is widespread in the literature (Auffhammer & Schlenker, 2014; Burke & Emerick, 2016; Hsiang, 2016; Hultgren et al., 2025; Schlenker & Roberts, 2009)

Comment Type: Technical

DOE CWG STATEMENT: *“Deschênes and Greenstone (2007) looked at agricultural profits instead of land values and reached conclusions similar to Mendelsohn et al. (1994), namely that past climatic variations had relatively little effect on farm profitability and that warming would likely yield small overall benefits for the U.S. agricultural sector. However, a subsequent exchange with critics led them (Deschênes and Greenstone 2012) to revise their conclusions and project potentially large losses in U.S. agriculture due to climate warming.”*

COMMENT: As is well known in the literature, the original Deschênes and Greenstone (2007) results discussed here were due to a severe data error in which weather data was not correctly matched to U.S. counties (as clearly documented in Fisher et al (2012) Figures 1 and 2). Thus the original Deschênes and Greenstone (2007) results should simply be ignored (though the important methodological contribution can be noted): the Deschênes and Greenstone (2007) results are the product of a widespread data error, not an actual empirical finding. Note: the change in results in Deschênes and Greenstone (2012) was not simply the result of an “exchange with critics” as stated in this report (phrasing which is open to many interpretations). Rather, the corrected findings in Deschênes and Greenstone (2012) are the result of correcting a severe and pervasive – and clearly documented – data error. The current phrasing in this report is misleading at best.

ACTION: The specific results from Deschênes and Greenstone (2007) should not be included in the report due to the well documented data error. The inaccurate “exchange with critics” statement should also be removed and the updated Deschênes and Greenstone (2012) results instead discussed as a correction to severe data errors in the original Deschênes and Greenstone (2007) publication.

Comment Type: Technical

DOE CWG STATEMENT: *“Burke and Emerick (2016) looked at temperature variations over 1980 to 2000 and argued that farmers were not as able to adapt to temperature changes as the Ricardian method assumes and that climate change would have large negative impacts on corn and soy yields. Schlenker and Roberts (2009) similarly argued that yield gains to past warming would not carry over to the future and corn and soy yields would sharply decrease this century due to climate change.”*

COMMENT: Burke and Emerick (2016) does not “argue” that farmers are not able to adapt to temperature changes: they explicitly *test* whether or not that is the case. They *find* that farmer adaptation is limited. Note: their test could result in a finding that farmers do substantially adapt; that is simply not what the data show. Similarly, Schlenker and Roberts (2009) do not “argue” that yields would sharply decrease under climate change, this is instead an empirical finding in

their work. The report does not discuss anything about the actual findings of these papers, implying that these are philosophical arguments.

An accurate summary of Burke and Emerick 2016 is as follows: “In Burke and Emerick (2016), the authors construct measures of short run heat shocks as well as long-run changes in heat exposure. If farmers adapt to long run changes in heat exposure (as they would under climate change), then yield losses under long-run heat changes should be significantly smaller than yield losses under short run (unexpected) heat shocks. Instead, Burke and Emerick (2016) finds that yield losses under both measures are nearly identical, leading them to conclude that the scope for climate change adaptation to heat extremes by U.S. farmers is limited.”

The empirical test in Schlenker and Roberts (2009) could have found that yields increase under future climate change, or are unaffected by climate change – but does not, in fact the data support the conclusion that U.S. corn, soybean, and cotton yields will decrease under future warming. Note that this result has proved extremely robust (see for example reviews Auffhammer and Schlenker 2014; Hsiang 2016).

ACTION: The report authors need to substantively discuss the findings of Burke and Emerick (2016) and Schlenker and Roberts (2009) and the empirical tests that they employ.

COMMENT: This report incorrectly attributes the finding “yield gains to past warming” to Schlenker and Roberts (2009). Schlenker and Roberts (2009) do not find “yield gains to past warming” as that is not a topic that paper studies. Historical yields have risen, but that is due to technology development (Pardey & Alston, 2020).

ACTION: The statement “*Schlenker and Roberts (2009) similarly argued that yield gains to past warming*” should be removed.

Page 104

Comment Type: Technical

DOE CWG STATEMENT: “*Two recent studies have argued that pessimistic findings such as these are not robust. Ortiz-Bobea (2019) argued that land values aggregate farm and non-farm influences and the latter need to be filtered out. He developed a data set using cash rents for agricultural activity as a measure of land value specifically for farming activity. Whereas the land value model implied future losses under climate warming, the same model estimated using cash rents did not, leading the author to conclude the pessimistic results were due to using an inaccurate measure of the returns to farming activity.*”

COMMENT: There are three main issues with the statement above: criticism of the methodology, the large uncertainty of the results is not acknowledged, and the larger body of work by the same author with opposite conclusions was omitted from this report. (Note that “Ortiz-Bobea (2019)” was actually published in (2020). For consistency with the DOE report, this

comment will refer to “Ortiz-Bobea (2019)”, but the report reference and citation should be corrected.)

Issue 1a: Methodological criticism #1: First, Ortiz-Bobea (2019) employs the same general method (cross sectional regression) as that employed by Mendelsohn et al (1994). Thus, the same general criticisms apply. Specifically, Ortiz-Bobea (2019) employs a cross sectional regression estimator that is widely recognized as vulnerable to confounding, or “omitted variables bias” as it is termed in the econometrics literature broadly (Angrist and Pischke 2008, Chapter 3; Wooldridge 2010 Chapter 4). This is a fundamental problem with the empirical approach employed and is also widely recognized in the literature on climate change and agriculture (see for example reviews Auffhammer and Schlenker 2014; Hsiang 2016).

ACTION: The report should clearly discuss the issue of confounding in the cross-sectional hedonic regression approach issue as a major caveat to the Ortiz-Bobea (2019) findings.

Issue 1b: Methodological criticism #2: The Ortiz-Bobea (2019) includes an important caveat that should be discussed in the report, a caveat which we copy in full here: *“As previously mentioned, a potential caveat of the current implementation is that the survey data targets cropland and pastures participating in the rental market, and not all cropland and pastures. While the data necessary to carefully analyze this selection problem are unavailable, one can speculate about microlevel selection patterns from aggregate data. Specifically, the fact that counties with better soils tend to exhibit a higher share of rented farmland (online supplementary figures S19 and S4) suggests that parcels with better soil quality are more likely to be rented out. This suggests that high-quality land may be overrepresented in each county. As a result, if land of poor quality is more vulnerable to climate change, then this truncation of the sample would bias Ricardian estimates upward.”* Note that the issue mentioned here is one of selection bias into the data, not bias due to omitted variables, and is thus a separate issue from the first substantive issue raised in this response.

ACTION: This issue of selection bias should be discussed in the report as a bias towards finding cash rent gains from climate change when in fact there may be none.

Issue 2: Large uncertainty of the results: The uncertainty in the Ortiz-Bobea (2019) findings is massive (see Ortiz-Bobea (2019) Figure 3a, 3b). For high warming RCP 8.5, rainfed cropland cash rents could decrease by over 50% or increase by over 90% according to the paper’s own results.

ACTION: This uncertainty in the results of Ortiz-Bobea (2019) should be explicitly acknowledged in the report.

Issue 3: Omission of larger body of work by the same authors with opposite conclusions: It is remarkable that the report cites the one paper by Ortiz-Bobea that finds (possible) profitability gains from climate change, while completely ignoring the plethora of papers by the same author that reach the opposite conclusion.

ACTION: If the report wishes to discuss Ortiz-Bobea 2019, equal weight should be given to that author's other work regarding agriculture and climate change. By order of citation counts, the top 5 papers studying climate change and agriculture by Ortiz-Bobea are: Ortiz-Bobea et al 2021, Ortiz-Bobea et al 2019, Gammans et al 2017, Ortiz-Bobea et al 2018, and Yang et al 2024.

Page 104

Comment Type: Technical

DOE CWG STATEMENT: *"Bareille and Chakir (2023) assembled a large data base on farm sale prices in France for properties that sold twice between 1996 and 2019. They could replicate pessimistic results showing negative effects of warming on agricultural land values using conventional econometric modeling. But by taking advantage of the repeat sales data, which provides information on site-specific changes in land prices, they found the results reversed and implied that climate change will be very beneficial for French agriculture. The authors concluded that, taking adaptation into account, a warming climate would yield positive benefits for French agriculture that were between two and 20 times larger than had previously been estimated. On average, with full adaptation, they concluded that climate changes under the medium RCP4.5 scenario could double the value of French farmland by 2100."*

COMMENT: This section of the DOE CWG Report addresses climate change and U.S. agriculture. Bareille and Chakir (2023) studied French agriculture. The gains from climate change estimated by Bareille and Chakir (2023) are notable. However, the authors note these gains are driven by crop switching into vineyards (Table 8) – a very high value crop that France is particularly well suited for.

ACTION: This report should remove the discussion of Bareille and Chakir (2023) because the vast majority of agricultural lands in the U.S. are not well-suited to vineyard planting due to soil constraints, limiting the applicability of Bareille and Chakir (2023) in the U.S. context. If the report authors choose to keep the reference to Bareille and Chakir (2023) then they need to include the fact that the results are specific to soils which support vineyards and not broadly applicable to U.S. contexts.

COMMENT: The statement that Bareille and Chakir (2023) estimated benefits that are *"between two and 20 times larger than had previously been estimated"* is incorrect: the comparison in the paper is to pooled cross sectional estimates provided in that same paper; it is not a comparison to *"previously"* estimated results. Further, the pooled cross sectional estimates in Bareille and Chakir (2023) (provided for comparison with their preferred estimates) have known omitted variables bias issues discussed by Bareille and Chakir in the paper. The *"between two and 20 times larger"* comparison discussed in the DOE CWG Report is thus accurately understood as a critique of the cross sectional regression approach--that is, a critique of Mendelsohn et al 1994 and Ortiz-Bobea 2019.

ACTION: The report should correct this mistake and remove reference to the “two and 20 times larger” comparison.

Page 105

Comment Type: Technical

DOE CWG STATEMENT: *A major deficiency of all these studies, however, is that they omit the role of CO₂ fertilization. Climate change as it relates to this report is caused by GHG emissions, chiefly CO₂. The econometric analyses referenced above focus only on temperature and precipitation changes and do not take account of the beneficial growth effect of the additional CO₂ that drives them. As explained in Chapter 2, CO₂ is a major driver of plant growth, so this omission biases the analysis towards underestimation of the benefits of climate change to agriculture.*

COMMENT: It is true that the studies the report cites do not account for CO₂ fertilization. However, this does not represent a “major deficiency,” as the DOE CWG Report claims, for two reasons. First, recent work not cited in the report does exactly this. Hultgren et al. (2025) estimated yield losses accounting for adaptation, and accounting for CO₂ fertilization, and found that yield losses at global scale and for the U.S. persisted for maize, soybeans, wheat, sorghum, and cassava. This result of global-scale yield loss was true for both moderate (RCP 4.5) and high (RCP 8.5) future emissions. Only rice was protected from future warming at global scale and in the U.S., however rice is not a major U.S. crop (and South and Southeast Asia maintain their comparative advantage in rice production relative to the U.S.). See Hultgren et al 2025 Figure 3, and Supplementary Figures S13 and S14. This analysis was not biased “towards underestimation of the benefits of climate change to agriculture,” and it found that accounting for CO₂ fertilization did not alter the finding that climate change is damaging to U.S. and global staple crop output. Note also that other studies have found less optimistic results for rice than did Hultgren et al 2025 – see for example Muehe et al 2019, Figure 1, which found losses to rice yields under future climate conditions in plant-growth experiments even after accounting for gains from CO₂ fertilization.

Second, the DOE CWG statement implies that including CO₂ fertilization effects will overcome any negative effects of CO₂ driven climate change. As highlighted in comments related to the next section (Section 9.2), the authors of this report stop before they get to the end of the issue. Elevated CO₂ operating alone does increase crop yields, but **only under non-stress conditions (see Ainsworth and Long (2021))**. Increasing temperatures and related climate-driven meteorological changes will certainly lead to higher stress conditions that diminish or erase CO₂-induced yield gains (Auffhammer & Schlenker, 2014; Hsiao et al., 2019; Hultgren et al., 2025; Jägermeyr et al., 2021; Lobell et al., 2011; Lobell & Field, 2007; Muehe et al., 2019; Zhu et al., 2023). This fact limits the extent to which CO₂ fertilization can mitigate yield losses under future warming (Ainsworth & Long, 2021). The lack of discussion about these issues in this section is glaring.

The current consensus – across a range of methodological approaches – is that CO₂-induced climate change will lead to net yield declines in major agricultural regions in the U.S. and globally (Auffhammer & Schlenker, 2014; Hsiao et al., 2019; Hu et al., 2024; Hultgren et al., 2025; Jägermeyr et al., 2021; Lobell et al., 2011; Lobell & Field, 2007; Su et al., 2023; Zhao et al., 2017), and in some regions, declines have already occurred in response to extreme temperatures (Brás et al., 2021).

ACTION: The revised report should acknowledge and discuss each of the two points outlined in the comment.

Finally, when referring to “all of these studies”, this report discusses a total of seven studies. However, the econometric literature on climate change and U.S. agriculture is vast, and this report ignores nearly all of it. It is understandable that not every study on the topic can be included in this report. However, that does not excuse the report’s propensity to ignore most of the relevant literature: literature reviews exist for exactly the purpose of summarizing a vast literature.

ACTION: This report should summarize the discussions of recent reviews on this topic such as Auffhammer and Schlenker (2014); Hsiang (2016); Carleton and Hsiang (2016); and the discussion of the literature in Hultgren et al (2025).

9.2 Field and laboratory studies of CO₂ enrichment

Section 9.2 begins on page 105 and ends on Page 106. This section of the DOE CWG report overstates the benefits that elevated CO₂ will have for crops in the U.S. for reasons described below.

Page: 105

Comment Type: Technical

DOE CWG STATEMENT: *“One of the ways the effect of CO₂ on crop growth has been studied is through “free air enrichment experiments” or FACE plots, in which small sources of CO₂ are placed in fields surrounding plants and the growth response to elevated CO₂ under varying weather conditions are recorded. Ainsworth et al. (2020) summarizes results from about 250 such studies. They found that elevation of CO₂ by 200 ppm caused an average 18 percent increase in crop yield in C3 plants. C4 plants exhibited benefits mainly under drought conditions.”*

COMMENT: The statement that elevating CO₂ by 200 ppm caused an average 18% increase in C3 crop yields fails to acknowledge the caveat clearly stated in the abstract of Ainsworth and Long (2021) that “elevation of [CO₂] by ca. 200 ppm caused a ca. 18% increase in yield **under non-stress conditions.**” (Note: the DOE CWG report incorrectly referred to the Ainsworth and Long (2021) publication as Ainsworth et al. (2020)). When plants had adequate water and

nutrients and were not subjected to warmer temperatures, elevated CO₂ was able to increase yields, on average, by 18%. However, when plants experienced stress in combination with elevated CO₂, the yield increases were suppressed and in some cases erased (see Section 4 in Ainsworth and Long (2021)). As CO₂ concentrations increase, they will not be the only factor that changes in the Earth system. Temperatures will warm and weather patterns will alter, layering stress on top of increased CO₂ concentrations.

It is disingenuous to overlook these co-occurring factors and focus on the isolated impact of CO₂ on crop yields under non-stress conditions. Indeed, drought has become both more severe and frequent due to climate change in the western US, a site of ample crop production, and is projected to be even more so in the future; see response to Section 6.7 for more details and references. Overall, yield declines are expected under future climate conditions. Multiple greenhouse studies have looked at how CO₂ will interact with elevated temperature (e.g., Muehe et al., 2019, and studies cited by Zhu et al. 2023), and numerous process-based and statistical modeling studies have investigated how CO₂ coupled with water stress, vapor pressure deficit, temperature, etc. will affect yields (e.g., Hu et al., 2024; Hsiao et al., 2019; Jägermeyr et al., 2021). Recent work by Hultgren et al. (2025) finds that substantial losses in agricultural yields – both for the U.S. and the globe – are expected in all major food crops except for rice, even after accounting for CO₂ fertilization and farmer adaptation potential.

ACTION: The report needs to acknowledge and discuss the current consensus – developed with a range of methodological approaches – that in the major agricultural growing regions of the U.S. (and in most parts of the world), CO₂-induced climate change will lead to yield declines (Auffhammer & Schlenker, 2014; Hsiao et al., 2019; Hu et al., 2024; Hultgren et al., 2025; Jägermeyr et al., 2021; Lobell et al., 2011; Lobell & Field, 2007; Su et al., 2023; Zhao et al., 2017)

Page: 105

Comment Type: Technical

DOE CWG STATEMENT: *“In addition to FACE plot experiments there have been thousands of laboratory experiments on the effects of CO₂ on all kinds of plant growth. Here we review some of the results on key U.S. agricultural crops.”*

COMMENT: The four paragraphs starting with the statement above discuss laboratory experiments, citing from a website co2science.org. This website does not produce peer-reviewed research but rather compiles cherry-picked examples from the literature. Cherry picking only the most positive responses is guaranteed to give an overly optimistic view of crop yield CO₂ enhancement. There is a reason that FACE experiments are the scientific standard - running laboratory experiments in small pots in greenhouses is well known to give a wide variation in results because of large variation in conditions. In fact, the correlation coefficient for key photosynthesis and productivity traits between plants grown in controlled greenhouse conditions and those grown in field settings is relatively low (0.26) (Poorter et al., 2016), with

greenhouse studies tending to result in larger yield responses to elevated CO₂ than FACE experiments (Ainsworth and Long, 2021).

At issue is not whether elevated CO₂ increases plant productivity, but whether the yield boost associated with elevated CO₂ is at a sufficient magnitude to counteract damage from other aspects of climate change, such as yield loss associated with warming. The magnitudes cited in this section are well above the consensus of the rigorous FACE studies, which themselves often represent only non-stress conditions and thus ignore the negative effects of co-occurring increases in temperature and changes in water availability (see comment above). For example, this section in the DOE CWG Report states that soybean, maize, and wheat would increase under +300ppm by 50.9%, 23.7%, and 67.6%. FACE experiments show an average response of 21%, 0%, and 14% for +200ppm, respectively (Ainsworth and Long 2021). Scaling to 300 ppm would give roughly 30%, 0%, and 21% for FACE, which is far less than this section cites for all three crops.

It is also worth noting that the numbers they cite from the non-peer-reviewed co2science.org website are not the same as the numbers currently reported on the website. The actual values given currently on the website for +300ppm for soybean, maize, and wheat are 47.9%, 32.1%, and 38.5%.

ACTION: The report should not rely on a review of the literature that has not been peer reviewed. Since FACE experimental data are available for assessing the impact of elevated CO₂ on crop yields, the authors should rely on yield results from FACE experiments and not solely rely on numbers from greenhouse experiments.

ACTION: The authors need to expand their consideration of how climate change will impact yields to include more than CO₂ operating alone. The current consensus – across a range of methodological approaches – is that CO₂-induced climate change will lead to net yield declines in major agricultural regions in the U.S. and globally (Auffhammer & Schlenker, 2014; Hsiao et al., 2019; Hu et al., 2024; Hultgren et al., 2025; Jägermeyr et al., 2021; Lobell et al., 2011; Lobell & Field, 2007; Su et al., 2023; Zhao et al., 2017), and in some regions, declines have already occurred in response to extreme temperatures (Brás et al. 2021)

Page: 106, Figure 9.1 and section labeled “Further evidence”

Comment Type: Technical

DOE CWG STATEMENT: “A 2021 report from the U.S. National Bureau of Economic Research (Taylor and Schlenker 2021) used satellite-measured observations of outdoor CO₂ levels across the United States, matched to county-level agricultural output data and other economic variables. After controlling for the effects of weather, pollution and technology the authors concluded that CO₂ emissions had boosted U.S. crop production since 1940 by 50 to 80 percent, attributing much larger gains than had previously been estimated using FACE experiments. They found that every ppm of increase in CO₂ concentration boosts corn yields by 0.5 percent, soybeans by 0.6 percent, and wheat by 0.8 percent.”

COMMENT: The Taylor and Schlenker (2021) manuscript described as the sole citation in the “further evidence” section and replicated in Fig. 9.1 has not yet been peer-reviewed, but is publicly available as a working paper (we note that the text refers to the year of the manuscript as 2021, but the reference list cites the year as 2023). Peer review is an important part of the scientific process as it can address many methodological and other concerns that are likely to arise with this paper. Specifically:

- (1) The Taylor and Schlenker estimates of CO₂ response are very noisy, so that the 90% confidence interval nearly includes 0, and certainly includes the responses (of ~0.1% yield increase per ppm) seen in FACE experiments (Ainsworth and Long 2021). The authors rely heavily on the point estimates for their conclusions, but the Taylor and Schlenker results have very wide error bars, meaning that the approach cannot be considered robust enough to challenge the general results from FACE experiments. Some of their specifications that include time trends even include 0% yield increase per ppm in the 90% confidence interval. (Figure 6 in Taylor and Schlenker (2021)).
- (2) Taylor and Schlenker use as a measure of CO₂ exposure estimates from the OCO-2 satellite, which provide total column rather than surface CO₂. It is very likely that these column totals underestimate the true amount of variation at the surface, which is what crops experience. As the authors themselves state in the working paper, “If CO₂ disturbances at ground level phase out in altitude, then the variation we observe in the satellite data would be smaller than the ground-level variation, thereby leading to an upward-biased CO₂ fertilization coefficient.” This bias has not been adequately dealt with, and is likely to be revised in a subsequent version of the working paper (author communication). Initial updates by Taylor and Schlenker presented at a recent conference indicate their estimated CO₂ fertilization gains will be revised downward substantially upon correcting for this issue. Again, this is a reason to not rely on studies that have not yet passed through peer review.
- (3) Taylor and Schlenker do not state in the manuscript that “CO₂ emissions had boosted U.S. crop production since 1940 by 50 to 80 percent,” as is claimed in the DOE report
- (4) The DOE report omits the fact that the Taylor and Schlenker paper also states “We reiterate that climate change will likely have a negative impact on agriculture in aggregate, especially in regions exposed to extreme heat”
- (5) Taylor and Schlenker are attempting to find the signal of CO₂ driven enhancement of yield from extremely small perturbations of CO₂ (on order less than 4ppm), and have not attempted to quantify other environmental factors which may co-vary with these small CO₂ variations such as changes in clouds and solar radiation.

ACTION: The authors of the DOE CWG report should remove all reference to this study as it is not peer-reviewed and has issues that the study authors are actively working to address.

9.3 Crop Modeling Meta-Analyses

Page: 106-107

Comment Type: Technical

COMMENT: Section 9.3 purports to summarize evidence from crop-modeling meta-analysis relevant to understanding “Climate Change and U.S. Agriculture”. However, the section discusses results from a single study (McKittrick, 2025) and how they compare to one set of results from an earlier study (Moore et al., 2017). This approach presents a partial, incomplete, and dated representation of current understanding. The authors omit consideration of many more recent studies and related lines of evidence:

- Moore et al. (2017) used two alternative approaches to develop conclusions regarding the impact of climate change on the global agricultural sector. This section speaks to one of these approaches (modeling based on the Challinor et al. (2014) dataset) but not the other one, which was based on gridded runs of an ensemble of process-based crop models under the Agricultural Model Intercomparison Project (AgMIP, Rosenzweig et al., 2014). Although this second approach produced slightly smaller estimates of crop damage than the meta-analysis, it also supported an overall upward revision in the estimate of climate change impacts on the agricultural sector, relative to those included previously based on estimates from the FUND Integrated Assessment Model.
- Since Challinor et al. (2014) there has been another full assessment round of the IPCC. The relevant chapter in the IPCC 6th Assessment Report (Bezner Kerr et al. 2022) was supported by a much expanded and updated review of the scientific evidence on yield response to changing climate conditions (Hasegawa et al., 2022). This new dataset includes approximately 4 times as many observations as the previous Challinor et al. (2014) dataset. Li et al. (2025) performed a meta-analysis of this dataset using approaches similar to Moore et al. (2017). They find net declines in global yields for major crops, accounting for projected changes in temperature, precipitation, and CO₂, even under relatively low emissions scenarios.
- There are multiple new lines of evidence on the influence of climate change on the global agricultural sector, including a global statistical analysis (Hultgren et al. 2025) and a new round of process-based modeling from AgMIP (Jägermeyr, et al. 2021), which reports that negative climate impacts on crops emerge earlier in the newer generation of models, despite the additional latter finding that these models still underestimate the impacts of extreme events on crop production (Heinicke et al., 2022).

ACTION: This report presents a partial, incomplete, and dated representation of current understanding of evidence of climate impact on agriculture from crop-modeling. The authors should provide a more comprehensive and current assessment of evidence on the effects of climate change on the global agricultural sector, inclusive of references given above.

Page: 106

Comment Type: Technical

DOE CWG STATEMENT: “*Notwithstanding the abundant evidence for the direct benefits of CO₂ and of CO₂-induced warming on crop growth,...*”

COMMENT: This statement is unsupported by the content of the DOE CWG Report (see response to a similar statement made by the DOE CWG report in the Chapter Summary on pg

104) and it does not align with current understanding. The current consensus – across a range of methodological approaches – is that CO₂-induced climate change will lead to net yield declines in major agricultural regions in the U.S. and globally (Auffhammer & Schlenker, 2014; Hsiao et al., 2019; Hu et al., 2024; Hultgren et al., 2025; Jägermeyr et al., 2021; Lobell et al., 2011; Lobell & Field, 2007; Su et al., 2023; Zhao et al., 2017), and in some regions, declines have already occurred in response to extreme temperatures (Brás et al. 2021)

ACTION: The authors should remove the statement that there is abundant evidence that CO₂-induced warming will be a net benefit to U.S. agriculture.

Page: 106

Comment Type: Technical

DOE CWG STATEMENT: *“in 2023 the U.S. Environmental Protection Agency (EPA 2023) boosted its estimate of the Social Cost of Carbon (SCC) about five-fold based largely on a very pessimistic 2017 estimate of global agricultural damages from climate warming (Moore et al., 2017)”*

COMMENT: This statement that findings from Moore et al. (2017) drove the overall Social Cost of Carbon (SCC) revision estimated by the EPA is unsupported. EPA (2023) introduced many scientific and economic improvements to the calculation of the Social Cost of Carbon (SCC), implementing most of the recommendations from a 2017 National Academies of Sciences report. These improvements include 1) probabilistic projection of socio-economic and emissions trajectories; 2) a much-improved representation of the climate system calibrated to the current ensemble of General Circulation Models (GCMs) and including uncertainty in climate system parameters; 3) updates to damage representation, including three alternative damage modules all using distinct estimation approaches. All these changes interact non-linearly within the SCC calculation, meaning the unique attribution of SCC changes to individual modeling changes, as is done in the referenced statement, is impossible.

The agricultural damage function from the GIVE model, based on Moore et al. (2017), is only one of four damage sectors within GIVE, which in turn is only one of three different damage modules used in the 2023 EPA analysis. Even if, hypothetically, agricultural damages within the GIVE model were completely eliminated, this elimination would result in approximately a \$90 per ton change to 1/3 of the damages. A back of the envelope calculation suggests this change would move the 2030 SCC from \$230 per ton to \$200 per ton (under a 2% discount rate, based on values in Figure 3.1.1 EPA 2023 and Rennert et al. (2022)). Therefore the statement that the 2023 EPA update to the SCC was driven largely by agricultural damages estimates in Moore et al. (2017) is entirely unjustified.

ACTION: The authors should remove this incorrect statement from the report

Page: 107

Comment Type: Reference

DOE CWG STATEMENT: “*McKitrick (2025) re-examined the Moore et al. database*”

COMMENT: The dataset in question was compiled and published by Challinor et al. (2014), used to support analysis in the IPCC 5th Assessment Report Food Security Chapter (Porter et al. 2014). It is inaccurate to refer to it as the Moore et al. dataset

ACTION: Correct all references and discussion within text to refer to the Challinor et al. (2014) dataset.

Page: 107

Comment Type: Technical

DOE CWG STATEMENT: “*McKitrick (2025) re-examined the Moore et al. database and found that, while it claimed to cover 1,722 studies, only half the entries (N=862) had complete records*”

COMMENT: Nowhere in Moore et al. (2017) is it claimed that 1,722 observations were used for the analysis. Moore et al. (2017) report using 1,010 observations, derived from the subset of Challinor et al. (2014) data relevant to the 4 crops studied (rice, wheat, maize and soybeans), where complete data was either present or could be inferred from reported information.

ACTION: Correct the statement to reflect that Moore et al. (2017) report using 1010 observations from the Challinor et al. (2014) database.

Page: 107

Comment Type: Technical

DOE CWG STATEMENT: “*The crop yield projections incorporating the newly available data changed considerably.*”

COMMENT: This statement is not supported by the referred to plot (Fig. 9.2). In most cases, particularly for most relevant near-term warming levels of 1, 2, and 3 degrees, uncertainty bounds of estimates from the two studies overlap. The one exception is soybeans, which is a smaller component of both calories and value share in agriculture than wheat, maize or rice.

ACTION: The authors should either remove this statement or perform the appropriate statistical test to determine at what confidence level the two versions of crop response functions (from Moore et al., 2017 and McKitrick, 2025) can be distinguished from each other at each level of warming.

Page: 107

Comment Type: Technical

DOE CWG STATEMENT: *“As shown in Figure 9.2, whereas the partial data set implied warming would decrease yield (blue lines), the complete data set implied constant or increase global yields, even out to 5°C warming (green lines).”*

Figure 9.2 and this description omit relevant information needed to infer the overall response of U.S. Agricultural yields to temperature, as outlined in the following specific comments:

COMMENT: Econometric specifications in both McKittrick (2025) and Moore et al. (2017) include interactions with baseline temperature, meaning estimated warming responses might be different in warm vs cool locations. Figure 9.2 does not identify what baseline temperature is used, nor does it clarify how the responses might look different in other locations.

ACTION: The authors should specify the baseline temperatures used for plotting the response functions in Figure 9.2 and state how the chosen functions relate to temperature conditions for U.S. agriculture, given U.S. agriculture is the topic of the section. Ideally the authors should plot response functions for baseline temperatures typical of U.S. agriculture. The authors also need to describe what confidence intervals are shown in the plotted error bars and clarify whether these response functions are inclusive of CO₂, adaptation, and temperature effects, or show only the temperature response.

COMMENT: Since response functions in both McKittrick (2025) and Moore et al. (2017) allow for heterogeneous, non-linear responses across different baseline temperatures, the implications for global yields cannot be inferred from the single set of response functions shown in Figure 9.2, unless these responses have been aggregated up on a production-weighted basis across all global growing regions.

ACTION: The authors should explain how they inferred the aggregate global yield response from the heterogeneous responses estimated in McKittrick (2025). Since Section 9 is on “Climate Change and U.S. Agriculture” they should explain how the U.S. yield response is distinct from the global yield response.

COMMENT: This statement incorrectly interprets the results of McKittrick (2025) presented as the green lines in Figure 9.2 as showing an increase in global yields. In all but one data point (Wheat at 1 °C change in temperature) the error bars cross the x-axis where yield change is 0%. The correct interpretation of the presented results would be that the complete data set implied only constant global yields, not increasing yields.

ACTION: The authors of the DOE CWG report need to remove “or increase” from the statement such that the sentence correctly states the data set, as presented, only “implied constant global yields.”

9.4 CO₂ fertilization and nutrient loss

Section 9.4 begins on page 107 and ends on Page 109. This section of the DOE CWG report minimizes the negative impacts that rising CO₂ levels and associated warming temperatures will have on the nutrient quality of crops to conclude that rising CO₂ levels and CO₂-induced warming will be a net benefit to U.S. agriculture.

As detailed below, this section misinterpreted many of the cited publications — including a publication (Ebi et al., 2021) that we and others co-authored — and failed to consider literature showing that elevated CO₂ and associated warming can increase toxin levels in crops, not just decrease nutrient density. Point-by-point responses are provided to statements in the DOE CWG report in this section.

Page: 107

Comment Type: Technical

DOE CWG STATEMENT: *“Evidence has shown that CO₂ -induced biomass gains are sometimes accompanied by reductions in the concentrations of protein and other key nutrients such as iron and zinc (Ebi et al. 2021).”*

COMMENT: This statement conflates evidence from two specific groups of plants, one of which consistently sees reductions in protein and nutrients under CO₂ and the other of which rarely shows response, to make the results sound less consistent. All plants absorb carbon dioxide from the atmosphere, using photosynthetic pathways to break down that carbon dioxide into carbon and oxygen, and then using the carbon to grow. Eighty-five percent of plants use a photosynthetic pathway that, based on biochemical characteristics, is termed C3; these C3 plants include important crops such as wheat, rice, barley, oats, rye, soybean, and potatoes. Field experiments with wheat and rice under a doubling of CO₂ from preindustrial concentrations demonstrate that protein declines by about 10%, B-vitamins by as much as 30%, and micronutrients by about 5% (see Ebi et al. 2021 and associated references). Wheat and rice each provide about 20% of calories consumed worldwide, with wide regional variability (Awika, 2011; Shiferaw et al., 2013). Corn, sorghum, and millet use a different photosynthetic pathway (C4) and are not expected to experience declines in nutrient density with higher CO₂ concentrations. The DOE CWG report conflates these two photosynthetic pathways into “sometimes” without being clear that declines in nutrient density are consistently seen under elevated CO₂ for C3 crops (Loladze, 2002, 2014; Loladze et al., 2019; Myers et al., 2014; Taub et al., 2008; J. Wang et al., 2019, 2020; Zhu et al., 2018), which are widely consumed in the USA.

The DOE CWG report also ignores a key fact raised in Ebi et al. (2021) that elevated CO₂ and elevated temperature can increase toxins such as arsenic and cadmium in crops (Dhar et al., 2020; Farhat et al., 2021, 2023; Guo et al., 2011; Muehe et al., 2019; J. Wang et al., 2019; Y. Wang et al., 2023; Yuan et al., 2021), not just dilute nutrients. Ingestion of toxins in food results in illness, shortened life span, reduced quality of life, and death (Gibb et al., 2019).

ACTION: The report authors need to remove the word ‘sometimes’ from this statement and modify its wording to clarify the fact that declines in nutrient density are consistently observed under elevated CO₂ for C3 crops but rarely for C4 crops. In addition, the authors need to add a sentence (or section) that acknowledges the fact that research thus far indicates that elevated CO₂ and elevated temperature can increase toxin concentrations in crops.

Page: 107

Comment Type: Technical

DOE CWG STATEMENT: “*Some experiments have shown that the rising temperatures expected to accompany higher CO₂ levels will offset this loss (Köhler et al. 2019) although the evidence for this is mixed, as is the evidence that nutrient dilution observed to date is entirely attributable to higher CO₂ (Ziska 2022).*”

COMMENT: Some experiments have shown that rising temperatures expected to accompany higher CO₂ levels can offset nutritional losses (Köhler et al., 2019), and, while the DOE CWG report acknowledges that evidence for this temperature compensation is mixed, it fails to cite studies that found partial or no compensation in nutritional density when elevated CO₂ was crossed with elevated temperature (e.g., Jayawardena et al., 2021; J. Wang et al., 2019; Wei et al., 2021; Ziska et al., 1997).

ACTION: The report authors need to cite the studies that found partial or no compensation in nutritional density when elevated CO₂ was crossed with elevated temperature.

COMMENT: On the flip side of crop nutritional quality, increased temperatures are expected to increase toxin levels in crops. Wang et al. (2020) found that while warmer temperatures moderately mitigated the loss of nutrients associated with elevated CO₂, the warmer temperatures simultaneously increased Mn, Mo, Cr, Ni, Cd and Pb concentrations in rice and wheat. A study investigating arsenic contamination of rice found that grain arsenic concentrations were more elevated when elevated CO₂ was combined with elevated temperature than when either elevated CO₂ or elevated temperature operated alone (Muehe et al., 2019).

ACTION: The report authors should add a sentence (or section) acknowledging that increased temperatures are expected to increase toxin levels in crops. This sentence or section should cite Wang et al. (2020) and Muehe et al. (2019), at a minimum.

COMMENT: The second half of the statement above (i.e., “... as is the evidence that nutrient dilution observed to date is entirely attributable to higher CO₂”) draws an incorrect conclusion from Ziska (2022). Ziska (2022) presents a figure (Figure 1) that shows newer breeding lines of spring wheat have less percent protein, but that all the breeding lines have experienced declines in percent protein over the 20th century. Thus, Ziska (2022) acknowledges that breeding can change nutritional density but ultimately concludes “[CO₂] is directly affecting protein concentration separate from breeding history.”

ACTION: The report authors need to provide context for the statement that observed nutrient dilution is not entirely attributable to higher CO₂, acknowledging that actions like breeding can

alter nutrient density, while clarifying that elevated CO₂ will operate on top of these other factors, additionally reducing nutrient density.

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Comment Type: Technical

DOE CWG STATEMENT: “If nutrient dilution does occur under rising CO₂ levels, there are several adaptive strategies that could be pursued. First, selective breeding to raise micronutrient content is already established (Saltzman et al. 2017) and has proven to be a cost-effective agronomic strategy (Ebi et al. 2021).”

COMMENT: Biofortification via selective breeding has been used successfully to raise the zinc, iron, and vitamin A content of crops, per Saltzman et al. (2017). However, this approach is not a ‘proven’ agronomic strategy, cost-effective or otherwise, for addressing simultaneous nutrient dilution by elevated CO₂. Ebi et al. (2021) specifically stated, “An additional challenge for biofortification is the tendency of rising CO₂ concentrations to diminish the concentrations of multiple nutrients concomitantly (Loladze 2014a, 2014b) in contrast to biofortification that targets only one or a few selected nutrients.”

ACTION: The report authors need to clarify that selective breeding to raise micronutrient content is only established for a few selected nutrients and is not yet a proven strategy for addressing the simultaneous decrease of multiple nutrients triggered by elevated CO₂.

COMMENT: Further, biofortification cannot address the issue of increased toxin levels in crops associated with elevated CO₂ and CO₂-induced warming.

ACTION: The report authors need to add a sentence (or section) acknowledging that biofortification will not solve the issue of increased toxin concentrations in crops that is expected to occur with elevated CO₂ and CO₂-induced warming.

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Comment Type: Technical

DOE CWG STATEMENT: “Optimal strategies will be location-specific because they vary by crop, climate and soil type (Ebi et al. 2021).”

COMMENT: Developing new cultivars requires significant investments and generally take years (see CGIAR programs, for example, <https://www.cgiar.org>). Such programs will not be developed locally, nor will the investment make sense if the developed cultivar only applies to a specific location.

ACTION: The report authors need to add the comment above as a caveat. Additionally, the reference to Ebi et al. (2021) should be removed from this statement because it does not reflect any argument or point made within Ebi et al. (2021).

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Comment Type: Technical

DOE CWG STATEMENT: *“Second, fortification of food products with micronutrients is already routine. Folic acid (a B vitamin) is added to flour and many other foods; iodine is added to table salt, most commercial breakfast cereals are fortified with iron and numerous vitamins, etc. Third, dietary supplements in the form of multivitamin tablets are inexpensive, widely-available and routinely consumed.”*

COMMENT: Fortification and dietary supplements do not currently alleviate nutrient deficiencies; therefore, it is unlikely that such approaches will alleviate nutrient deficiencies in the future, particularly if they are exacerbated by lower crop nutrient density. For example, 30% of women and girls worldwide (15-49 years) currently have iron-deficiency anemia (World Health Organization, 2025), including nearly 40% of women and girls (12-21 years) in the U.S. (Weyand et al., 2023). These deficiency exist despite decades of dietary supplement availability (Macdougall, 2017).

The DOE CWG report ignores that high CO₂ concentrations affect a wide range of macro- and micronutrients beyond iron and zinc, such as lithium (for mental health), magnesium (for muscle and nerve function, blood pressure regulation, bone health, and energy production), and others (Loladze, 2014). Dietary supplements do not address these critical contributions to hidden hunger (Wallace et al., 2014). U.S. government guidelines emphasize that supplements are not an adequate substitute for a nutrient dense diet (U.S. Department of Agriculture & U.S. Department of Health and Human Services, 2010).

Further, fortification of food or use of supplements will not address the health risk posed by increased toxin concentrations in grain associated with elevated CO₂ and CO₂-induced warming.

ACTION: When discussing fortification and dietary supplements, the report authors need to add the important context described above that while these approaches have been in place for decades, they currently fail to fully alleviate nutrient deficiencies that exist within the U.S. and across the globe, and that these approaches cannot alleviate risks posed by increased toxin concentrations.

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Comment Type: Technical

DOE CWG STATEMENT: *“One concern about reliance on adaptive strategies is whether they are feasible in low-income countries. Micronutrient deficiency is already a problem in the developing world and dietary supplements have proven to be an effective low-cost response (Ebi et al. 2021).”*

COMMENT: As noted in the previous comment, micronutrient deficiency is a health problem in developing and developed countries; dietary supplements have not solved the problem. Micronutrient deficiency is expected to increase with elevated CO₂ (Beach et al., 2019; Smith & Myers, 2019; Weyant et al., 2018; Zhu et al., 2018). As supplements have been unable to fully address the current deficiencies in micronutrients, it is unlikely they will successfully ameliorate a future increased health burden caused by nutrient dilution in crops. In addition, as noted in the

previous comment, supplements will not address the health issues posed by increased toxin concentrations in grain expected with elevated CO₂ and CO₂-induced warming.

ACTION: The report authors need to remove the statement that dietary supplements have proven to be an effective low-cost response to micronutrient deficiency, or they need to find a source other than Ebi et al. (2021) to support this statement. Ebi et al. (2021) does not make this claim. Ebi et al. (2021) discuss dietary supplements but do not conclude they have “proven to be an effective low-cost response” to declining nutrient density in crops.

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Comment Type: Technical

DOE CWG STATEMENT: *“It should also be noted the IPCC emission scenarios that generate high levels of warming also involve strong income growth. The SSP scenarios 3 assume that, compared to 2005 levels, global per capita income will double by 2100 in the lowest growth case (SSP3), and in the highest emission case (SSP5) global per-capita income will grow nearly 16-fold. In that scenario even the poorest regions (Africa and the Middle East) end up with a per capita income of about US\$126,000, 70 percent higher than current U.S. per capita income (about US\$75,000). Consequently the same scenarios in which CO₂ levels increase the most are also those in which global poverty is largely eliminated, in which case all countries would be able to afford dietary supplements as necessary to address micronutrient deficiencies, if they arise and cannot be addressed using on-farm agricultural strategies.”*

COMMENT: The U.S. is one of the wealthier countries in the world, yet many U.S. citizens suffer from micronutrient deficiencies. Wallace et al. (2014) used data from the National Health and Nutrition Examination Survey (2007 – 2010) to determine that despite the fact that 51% of Americans consume multivitamin/mineral supplements with ≥ 9 micronutrients, many fail to meet the estimated average requirement for vitamin A (35%), vitamin C (31%), vitamin D (74%), vitamin E (67%), vitamin K (77%), calcium (39%), magnesium (46%), potassium (100%), and choline (92%). Bird et al. (2017) concluded that “Nearly one-third of the U.S. population is at risk of deficiency in at least one vitamin, or has anemia.” Growth and development of children and lifespan health depends on adequate intake of micronutrients. Decreasing the nutrient density of diets through continued emissions of CO₂ will exacerbate the situation, even with any associated income growth.

Ingestion of toxins in food is a global problem that affects the health of millions of people, including those living in wealthy countries (Consumer Reports, 2012, 2014; Gibb et al., 2019). A growth in income will not offset the health risk posed by contaminated food. It is expected that this health risk will grow as elevated CO₂ and CO₂-induced warming increase the toxin content of crops (Dhar et al., 2020; Farhat et al., 2021, 2023; Guo et al., 2011; Muehe et al., 2019; J. Wang et al., 2019; Y. Wang et al., 2023; Yuan et al., 2021).

ACTION: The report authors need to clearly state that relying on economic development in order to afford supplements will not fully address the health problems associated with declining nutrient density and increasing toxin concentrations in crops, both of which are anticipated to occur with elevated CO₂ and CO₂-induced warming. The report needs to acknowledge the

compelling body of research that documents the fact that supplements (and fortification) do not currently address nutrient deficiency or toxin exposure from food.

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Comment Type: Technical

DOE CWG STATEMENT: *“In summary, there is abundant evidence going back decades that rising CO₂ levels benefit plants, including agricultural crops, and that CO₂-induced warming will be a net benefit to U.S. agriculture.”*

COMMENT: There is abundant evidence that under ideal conditions (i.e., adequate nutrients and water and optimal temperatures), crop productivity increases with rising CO₂ levels (e.g., Ainsworth & Long, 2021). These increases diminish or disappear when conditions are non-ideal (i.e., nutrients are limited, water and temperatures are sub-optimal). As CO₂ concentrations increase, ambient temperatures will continue warming and weather patterns will shift, altering water and nutrient availability. It is not clear that boosts in productivity generated by elevated CO₂ will compensate for the damage to plant productivity caused by these other stressors. In many parts of the world, even with adaptation, crop yields are expected to decline (Hultgren et al., 2025). Further, discussed in the comments above, elevated CO₂ is associated with declining nutrient density in crops. Therefore, it is disingenuous to state that there is “abundant evidence going back decades that rising CO₂ levels benefit plants.” This statement cherry-picks the productivity boost to plants associated with rising CO₂ levels while ignoring the negative human health outcomes that will co-occur.

ACTION: The authors need to remove the claim from the DOE CWG Report that *“there is abundant evidence going back decades that rising CO₂ levels benefit plants, including agricultural crops, and that CO₂-induced warming will be a net benefit to U.S. agriculture.”* The scientific consensus is that CO₂-induced climate change—including rising temperatures, shifting weather patterns, and altered precipitation—will outweigh the benefits of CO₂ fertilization, leading to net yield declines across major agricultural regions in the U.S. and globally (Auffhammer & Schlenker, 2014; Hsiao et al., 2019; Hultgren et al., 2025; Jägermeyr et al., 2021; Lobell et al., 2011; Lobell & Field, 2007; Muehe et al., 2019; Zhu et al., 2023). Further, as outlined in the comments to Section 9.4 above, CO₂-induced warming is associated with nutrient dilution and increased toxin levels in crops. It is factually inaccurate to state or imply that “CO₂-induced warming will be a net benefit to U.S. agriculture.”

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Comment Type: Technical

DOE CWG STATEMENT: *“To the extent nutrient dilution occurs there are mitigating strategies available that will need to be researched and adapted to local conditions.”*

COMMENT: There are strategies, such as biofortification and supplementation, that can be employed to help mitigate nutrient dilution in crops, as discussed in Ebi et al. (2020). However, as outlined in the comments above, these approaches currently do not address nutrient deficiencies and therefore it is unrealistic to expect that they will be able to address future

nutrient deficiencies exacerbated by rising CO₂ levels and crop nutrient density. Further, these strategies will not solve the problem of increased concentrations of toxins in crops associated with increased CO₂ and/or CO₂-induced warming.

ACTION: The report authors need to clarify that these mitigation strategies will only partially address the health problems associated with reduced nutrient density in crops and will not address at all the problem of increased toxin concentrations in crops.

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Public Comment on the DOE Climate Report: Managing Risks of Extreme Weather

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Comment Type: Technical, DOE report: pp. 110-111

Summary: Sections 10.1 and 10.2 of the DOE report are poorly cited (with incorrect and non-peer reviewed citations) and reach overly broad conclusions not supported by the evidence. In particular, the authors say that climate risks are primarily driven by society's ability to adapt, drawing on data on economic costs of past disasters and excluding all other economic impacts of climate change, as well as failing to examine future scenarios of risk under different warming scenarios, and how these may affect human mortality and costs of adaptation. Changes are warranted to this section to address these deficiencies.

10.1 Socioeconomic Context

STATEMENT: "The evolution of climate risk in the U.S. has been dominated by societal factors, rather than by changes to the actual weather and climate hazards." (p. 110)

RESPONSE: See the response to Section 10.2 below for a more thorough response to this section and the claims made therein as they are largely overlapping with the context of Section 10.2. While this section includes some citations of natural disaster costs and technological tools (such as weather forecasting) and other adaptation methods used to reduce or alleviate these costs, no citations are given that actually describe or discuss the trends or causes of climate risks and climate costs. As such, while this section is supposed to provide a socioeconomic context for the management of extreme weather risks, it does not. Rather, this section makes bold claims without citation while at the same time providing citations for minor, inconsequential, or tangential claims (with incorrect citations as noted below).

What this section appears to be saying is that increases in economic damages over time are a function of a wealthier society incurring more economic damage (e.g., as real estate prices rise) and that adaptation to disasters is manageable (e.g. through improved weather forecasting). Both of these claims are debatable, with many other studies (not cited by DOE) showing increasing climate risks (economic and mortality) over time with higher temperature increases (IPCC 2022), and increasing challenges and limits to adaptation (Wasley et al. 2023). For example, rising temperatures and extreme heat events reduce labor productivity and increase mortality; between 2001 and 2020, exposure to high humid heat has been estimated to have caused over 90 billion PPP\$ losses per year due to decreased labor productivity in the US alone

(Parsons et al. 2022), dwarfing the estimates of some of the billion dollar disasters discussed in section 10.2. The Congressional Budget Office has also estimated that future sea level rise (of 4 feet) will cause regular flooding of residential property currently worth \$930 billion (CBO 2024). The DOE report does not show how these costs will be avoided through adaptation measures, such as building codes; the Fifth US National Climate Assessment clearly indicates that while adaptation efforts have increased, there are numerous barriers that will prevent the US from adapting to many climate related changes and damages (Wasley et al. 2023).

Further, just because the US has invested in better prediction and adaptation to extreme events does not mean that we will be able to do so indefinitely in the future, particularly as costs rise over time. To be most accurate, the DOE report must account for the full range of potential economic losses from climate impacts into the future, which it fails to do, including increases in mortality and morbidity, labor productivity, and declines in natural capital (Bastien-Olvera and Moore, 2020; Tol, 2023; Oda et al. 2023). For example, a (not-cited) Office of Management and Budget report has estimated that the United States gross domestic product could be reduced by 3 to 10 per cent by end of the century as a result of climate impacts, leading to annual Federal revenue loss of 7.1 per cent by the same time period, creating challenges in funding basic government functions (OMB, 2022). The Congressional Budget Office has released its own analysis, estimating a 4% reduction in GDP (CBO, 2024).

There is also an erroneous citation in this section. There is no paper by Deryugina and Hsiang (2023); a paper with the title given in the DOE report is Deryugina and Hsiang is from 2014 and is not about mortality reduction due to forecasting improvements. Deryugina and Hsiang (2014) provide economic analysis that “warmer daily temperatures will lower annual growth by 0.06-0.16 percentage points in the United States unless populations engage in new forms of adaptation”, furthering our assertion that economic costs are underestimated by the DOE report.

The DOI in the DOE bibliography for this citation (<https://www.nber.org/papers/w31361>) points to Shrader, Bakkensen and Lemoine (2023) which may be what the authors intended. Nonetheless, Shrader et al. (2023) state that “A large literature across economics, epidemiology, and other fields has shown that extreme temperatures are a major source of mortality”. The Shrader paper does not say that “Early warning systems, satellite monitoring, and improved weather forecasting have reduced deaths” as claimed in DOE (p. 110); Shrader et al. do say that improving forecasts (particularly for extreme heat) so that people can adapt by reducing their exposure through personal choices provides valuable economic benefits: “NWS forecasts save thousands of lives per year compared to less accurate alternatives and agents would pay billions of dollars for more accurate forecasts” (Shrader et al p. 34). Given that the current administration has cut more than 600 National Weather Service (NWS) staff positions and proposed cuts in the National Oceanic and Atmospheric Administration (NOAA) budgets, this is the opposite of what the paper suggests should be happening.

In conclusion, this section of the report must address the entirety of economic estimates of climate-related damage to the US, not limited to extreme events and disasters; discuss why the authors do not use the citations provided here; correct the incorrect citation and provide a

summary of the paper that aligns with the paper's authors own conclusions; and provide evidence and citations around the costs and limits to a range of adaptation actions, which are entirely missing.

Citations:

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Shrader, J. G., Bakkensen, L., & Lemoine, D. (2023). Fatal errors: The mortality value of accurate weather forecasts (No. w31361). National Bureau of Economic Research.

Tol, R. S. J. (2023). Social cost of carbon estimates have increased over time. *Nature Climate Change*, 13(6), 532–536. <https://doi.org/10.1038/s41558-023-01680-x>

Wasley, E. et al. 2023. Chapter 31: Adaptation. In Fifth US National Climate Assessment, US Global Change Research Program, Washington DC.

10.2 Data Challenges

STATEMENT: “[T]rends in losses from extreme weather and climate events are dominated by population increases and economic growth.”

RESPONSE: The statements made in this section rely completely on one author, Roger Pielke, Jr., via one peer-reviewed paper (Pielke, Jr., 2024) and one non-peer-reviewed Substack post titled “RIP NOAA’s billion dollar disasters”, but this is inadequate to prove any points regarding economic damage from disasters more widely. Essentially Pielke’s critique is about the way NOAA uses language regarding attribution to climate change from their ‘billion dollar damages’ dataset, as well as how this data was collected and adjusted (such as for inflation) in a transparent manner. What this section of the DOE report **does not show** is that disasters are decreasing or that climate change is not implicated in the rise of extreme events. Indeed, the frequency and intensity of many extreme events (including hot days and marine heat waves) are clearly increasing, with strong evidence these changes are driven by climate change (see other sections of this rebuttal report) (IPCC 2022). Indeed, in the Pielke (2024) study cited by the DOE, the author notes, “The point here is not to call into question the reality or importance of human-caused climate change – it is real, and it is important.”

Further, there are numerous datasets other than NOAA’s billion dollar disasters work that show the rise in climate change-related extreme events (e.g. observed trends in heat waves and extreme precipitation events, see Marvel et al. 2023). Other estimates that use attribution analysis show a clear increase in the number of extreme events attributable in part to climate change (Clarke et al. 2022) and to increased costs of damages globally (Newman and Noy 2023). Newman & Noy (2023) find that globally, climate change-attributed costs of extreme weather over 2000–2019 are estimated to be US \$2.86 trillion (an average of US \$143 billion per year). See additional economic damages in table 19.1 of the Fifth US National Climate Assessment (Hsiang et al 2023). Another recent paper estimated that mortality from tropical cyclone events in the US is widely underestimated, and that each event likely is responsible for indirect excess mortality in the range of 7,000-11,000 deaths per event (Young and Hsiang 2024).

Finally, it is notable that the NOAA “Billion Dollar Disaster” product is not discussed in detail at all, nor is there any representation of the scientific and technical debate or discussion. A primary citation for this database (Smith and Katz, 2013) is completely omitted from this section. Further,

the billion dollar dataset is likely an underestimation of climate damages, as it does not include environmental and ecosystem damages outside of agriculture and forestry, while the Fifth National Climate Assessment chapter 8 notes widespread risks to species and ecosystems which high economic and cultural values (McElwee et al. 2023). The DOE report statement that adaptation measures have “have lowered economic losses relative to GDP” (p. 111) is also unsubstantiated (no citation is provided), and is disputed by analysis by OMB and CBO cited above that looks are a wider range of economic losses than just those from extreme events and projects increasing costs and damages into the future (which the DOE report does not do).

Taken as a whole, this section is highly under-cited, and instead relies almost exclusively upon a single author, providing only a ‘cherry picked’ view. The representation of state-of-the-science attribution discussion and debate is completely omitted. The authors of this section must address deficiencies in citations, provide additional evidence for any claims that they make regarding the NOAA dataset and lowered economic losses relative to GDP attributable to adaptation measures, and address the existence of numerous other empirical datasets that show increased extreme events attributable to climate change (particularly heat days, marine heat waves, and extreme precipitation),

Citations:

Clarke, B et al. 2022 Extreme weather impacts of climate change: an attribution perspective *Environ. Res.: Climate* 1 012001

Hsiang et al. (2023) Chapter 19: Economics. In Fifth National Climate Assessment, US Global Change Research Program, Washington DC.

IPCC, 2022: Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001.

Marvel, K. et al. 2023. Chapter 2: Climate Trends: In Fifth US National Climate Assessment, US Global Change Research Program, Washington DC.

McElwee, P et al. 2023. Chapter 8: Ecosystems, biodiversity and ecosystem services. In Fifth US National Climate Assessment, US Global Change Research Program, Washington DC.

Newman, R., & Noy, I. (2023). The global costs of extreme weather that are attributable to climate change. *Nature Communications*, 14(1), 6103.
<https://doi.org/10.1038/s41467-023-41888-1>

Pielke Jr., R. (2024). Scientific integrity and U.S. 'billion dollar disasters'. *npj Natural Hazards*, 1, Article 12. <https://www.nature.com/articles/s44304-024-00011-0>

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<https://doi.org/10.1007/s11069-013-0566-5>

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Comments below about text summary and data graphic presented in section 10.2 of the DOE report.

Edited by A.E. Dessler, Texas A&M University

Page number: p. 111

Comments focus on Figure 10.1: “Losses per disaster as a % of Gross Domestic Product in NOAA’s billion-dollar disaster dataset (the version downloaded in July 2023), 1980 to 2022.”

Comment type: technical

(1) **introduction:** Section 10.2, Figure 10.1 comments directly on the U.S. Billion-dollar disaster research conducted at NOAA.

The reality of U.S. disaster losses is much more complex and nuanced than Figure 10.1 indicates. The frequency and cost of weather and climate disasters are increasing in the United States due to a combination of increased physical exposure, vulnerability, and hazards, the latter of which have been impacted by climate change via increasing the frequency and intensity of some types of extremes that lead to billion-dollar disasters:

"The intensification of these and other more extreme weather-climate events are intersecting with areas experiencing high levels of health disparities, social vulnerabilities, and increased exposure due to population growth in hazard-prone areas." (National Academies of Sciences, Engineering, and Medicine 2024)

The following sections highlight counterpoints on why the section 10.2, Figure 10.1 chart is presenting a misinformed view of U.S. disaster impacts.

(2) **background section:** The reality of U.S. disaster losses is much more complex and nuanced than the misleading Figure 10.1 shown in section 10.2. The following are examples that more clearly highlight the reality of U.S. disaster impacts.

As a first point, the figure 10.1 excludes U.S. disaster event data for 2023 and 2024, which have the highest and second highest count of billion-dollar disasters (inflation-adjusted) on record, 28 and 27, respectively (Smith, 2025). The average length of time between disasters fell from 82 days during the 1980s to 19 days during the last 10 years (2015-2024). Shorter time intervals between disasters can mean less time and resources available to respond, recover, and prepare for future events. This

increased frequency of events produces cascading impacts that are particularly challenging to vulnerable socioeconomic populations.

(3) **analysis:** Regional, state, or county-level discussions of the changing nature of risks and the numerous drivers are important for on-the-ground decision making to improve resilience. As Figure 10.1 in section 10.2 is at a national level, it is not particularly useful or illuminating for understanding the changing nature of weather and climate risk.

Secondly, Figure 10.1 shows disaster costs have a slightly negative growth rate over time when compared to the U.S. GDP. Given the more localized scale of extreme events, it is more informative to examine state GDP vs. state cost from billion-dollar disaster events. In any given year there are numerous states with billion-dollar disaster loss costs as a percentage of state GDP in the 2%-20% range (NOAA, 2025). In contrast, the inflation-adjusted cost per capita has increased from approximately \$90 per capita in the 1980s to more than \$400 per capita in the late 2010s and has remained at a high level in recent years (Smith, 2025).

There are several explanations for these trends, including increases in exposure (i.e., more assets at risk); increases in vulnerability (i.e., the amount of damage a hazard of given intensity, such as high winds, can cause at a location); and increases in the frequency and intensity of some types of extreme events due to human-caused climate change (USGCRP 2023). Regarding increased exposure, much of this growth and property development has continued in high-risk areas like coasts, the fire-prone wildland-urban interface in the West, and river floodplains. Areas where building codes are insufficient for reducing damage from extreme events are especially vulnerable to more extreme weather.

But we also know from extreme event attribution research that human-caused climate change is increasing the frequency and intensity of certain types of extreme weather that lead to billion-dollar disasters—most notably the rise in drought intensity in the western states, lengthening wildfire seasons in the western states, the potential for extremely heavy rainfall becoming more common in the eastern states and sea level rise, which is worsening hurricane storm surge flooding (please see responses to corresponding sections on drought, fire, extreme precipitation, sea level rise, and hurricanes and tropical cyclones).

As a result, over the last ten years (2015-2024), the U.S. has been impacted by 190 separate billion-dollar disasters that have killed more than 6,300 people (direct and indirect fatalities) and cost ~\$1.4 trillion in damage (Smith, 2025).

The U.S. has also been impacted by landfalling category 4 or 5 hurricanes in six of the last eight years (Harvey, Irma, Maria, Michael, Laura, Ida, Ian, Helene), which is among the highest frequencies of major hurricane landfall on record (NOAA/AOML, 2025). In 2024, the U.S. impacts from Hurricanes Helene and Milton alone were particularly destructive, causing more than \$100 billion in combined damage across Florida, Georgia, South Carolina, North Carolina, Tennessee, and Virginia over a two-week period. A number of these hurricanes are rapidly intensifying with record warm sea surface temperatures and causing flooding and wind damage many hundreds of miles inland - Ida in 2021 and Helene in 2024 (please see response to Section 6.2 regarding hurricanes).

Also, there were more billion-dollar extreme rainfall-induced flood events from 2010-2024 (26) than in the 1980s, 1990s and 2000s combined (19) - all flood events CPI-adjusted to 2024 dollars (NOAA, 2024). While increased population in or near floodplains has contributed to rising flood-related damages, a warming atmosphere - driven by climate change - is also a key factor. Warmer air holds more moisture, which raises the likelihood of extreme precipitation events and severe flooding (please see response to Section 6.4 regarding extreme precipitation).

To capture these growing trends, the NOAA billion-dollar disaster dataset represents the nation's authoritative database on major disaster costs incorporating the most robust public and private sector data sources and analysis. In performing these disaster cost assessments these statistics were developed using the most comprehensive public and private sector sources and represent the estimated total costs of these events -- that is, the costs in terms of dollars that would not have been incurred had the event not taken place. More than one dozen public and private sector data sources help capture the total, direct costs (both insured and uninsured) of the weather and climate events. These costs include: physical damage to residential, commercial, and municipal buildings; material assets (content) within buildings; time element losses such as business interruption or loss of living quarters; damage to vehicles and boats; public assets including roads, bridges, levees; electrical infrastructure and offshore energy platforms; agricultural assets including crops, livestock, and commercial timber; and wildfire suppression costs, among others.

(4) **action:** The DOE CWG authors should approach section 10.2 and Figure 10.1 using a more regional or state-based approach, and should examine the losses by inflation-adjusted, per-capita costs, which are increasing nationally, but will show variance state-by-state over time.

(5) **conclusion:** Even the most complete estimates should be considered economically conservative with respect to what is truly lost but cannot be fully measured due to a lack

of consistently available data. For example, no prominent national or global hazard databases consider losses to: natural capital or environmental degradation; mental or physical healthcare related costs; include the value of a statistical life (VSL); or supply chain, contingent business interruption costs.

References:

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National Academies of Sciences, Engineering, and Medicine. 2024. Compounding Disasters in Gulf Coast Communities 2020-2021: Impacts, Findings, and Lessons Learned. Washington, DC: The National Academies Press. <https://doi.org/10.17226/27170>

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Response to Section 10.3

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Summary

Below are technical comments to statements made within Chapter 10 of the DOE CWG Report. The page numbers associated with each statement/comment grouping indicates the page on which the statement starts.

Here we respond to the section “10.3 Mortality from temperature extremes”, providing a critical review of the statements and literature therein. This refers to the section found on pages 111-114 of the DOE CWG report.

This section makes the case that mortalities due to a changing climate are impacted by both changes in heat and cold extremes, and that adaptation needs to be considered in estimations of the mortality impacts. However, it relies upon a number of mis-representations of the current scientific understanding of human impacts of heat and cold. It also contradicts itself in the capacity of people to adapt. Lastly, this section focuses only on mortality impacts of heat and cold, neglecting the many other pathways by which climate change can affect both mortality and morbidity, for which there is an abundance of evidence.

10.3.1 Heat and cold risks

Comment 1

Original text:

Page 111 states “It stands to reason that extreme heat events would likely become more frequent while extreme cold events would become less frequent.”

Comment type: Technical

There is no scientific support provided for this statement.

Action:

Provide the scientific support for this statement.

Comment 2

Original text:

Page 112 states “Mortality during heat extremes is typically caused by heat stroke and heat exhaustion, while mortality during cold extremes typically stems from hypothermia and heart strain. Global mortality is substantially greater for cold conditions than for hot conditions (Zhao et al 2021, Ritchie 2024).”

Comment type: Technical

The second sentence, “Global mortality is substantially greater for cold conditions than for hot conditions” could be read as being about extremes, which could mislead readers.

The second sentence also does not convey the reason for this pattern, as explained in Alahmed et al. 2025. This also applies to other statements on page 112. As stated in Alahmed et al.:

“The pattern of higher cold-related deaths is primarily due to the specific form of the exposure–response relationship. For temperature and mortality, this relationship is non-linear, often described as U-shaped or J-shaped, indicating that both temperatures that are too cold and too hot increase mortality risk, separated by a comfortable or optimal temperature. In epidemiological studies, this optimal temperature is referred to as the minimum mortality temperature—ie, the point where deaths are lowest. From an epidemiological point of view, anything above this optimal temperature can be considered hot for a given location, whereas those lower are considered cold, which differs from people’s everyday sense of what constitutes a hot or cold day. For example, the optimal temperature often sits quite high within a location’s annual temperature range, meaning that days classified as cold in epidemiological terms could feel mild or even warm to some people.”

Using analyses from Barcelona as an example, Alahmed et al. continue:

“One explanation for why cold deaths were higher than heat deaths is mathematical: the area under the curve for heat is only a third of the total area ... Using numerical integration, the area under the curve was 2.745 for temperatures higher than 23.6°C and

5·287 for temperatures lower than 23·6°C. This finding partly explains why cold-related deaths are higher than hot-related deaths; however, it does not give the whole picture.

Looking at each day from 2000 to 2018 (6940 days) in Barcelona, most days had temperatures lower than the optimal temperature. When rounding temperatures to full digits, we see that the frequency of cold days (<23·6°C) far exceeds hot ones (>23·6°C; appendix p 1). Put another way, the figure ... shows that the contribution of cold days on attributable mortality is much larger than the contribution of a much more modest count of hot days.

However, what about the influence of temperature on the actual risk of death on a given day irrespective of how often it happens? We can assess the relative risk compared with the optimal temperature. During the study period in Barcelona, the coldest day had an average temperature of 1·4°C. On this day, the risk of cardiovascular death increased by 50% (relative risk 1·5) compared with the optimal temperature. Conversely, the hottest day had an average temperature of 32·1°C, which was associated with a 240% increase in cardiovascular death risk (relative risk 2·4). Such a day, however, was very rare, occurring only once in 19 years in Barcelona. Although the relative risk of death was higher on the hottest day, such extreme heat days were so infrequent that the attributable or excess deaths from heat remained much lower than those from more frequent cold. If very hot days were to occur more frequently, the excess deaths related to heat would be considerably higher.”

In short, the finding of greater cold-related mortality can be an outcome of the mathematical approach used, and results in part because of the greater frequency of cold conditions. In fact, rates of mortality are greater on hot days. The implication of the DOE CWG that climate change will not detrimentally affect mortality is not supported in recent science.

Action:

In order to address this issue, the DOE CWG needs to accurately include in the text the reasons for more cold-related mortality (e.g., a consequence of the mathematical approach used) and that mortality rates on hot days are higher. They also need to adjust the subsequent arguments made in this section to reflect this outcome.

Comment 3

Original text:

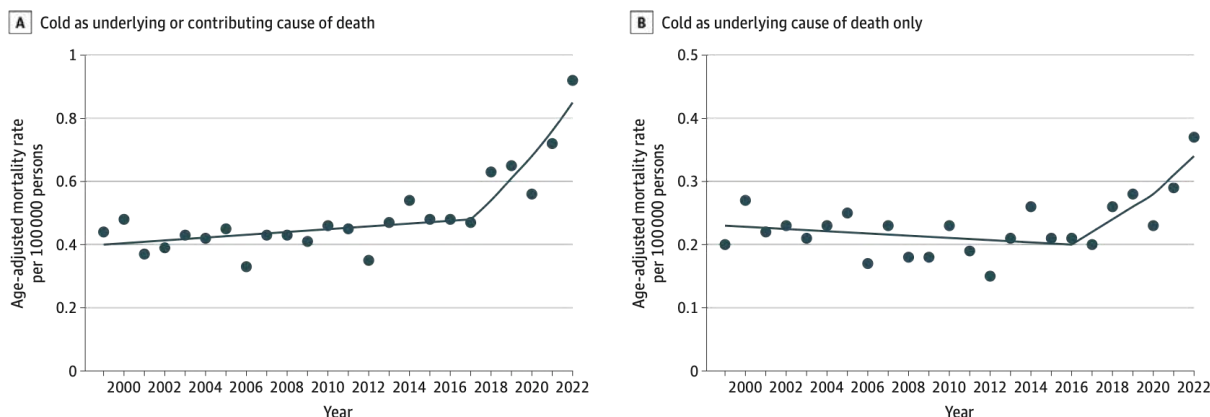
Page 112 of the DOE CWG states: “The U.S. EPA (citing data from the Centers for Disease Control) reports that on average over 1999 to 2015 there were 2.2 deaths per million Americans for which cold was listed as the main underlying cause and an additional 2.4 deaths per million for which cold was listed as a contributing factor (EPA 2025).”

Comment type: Editorial, technical

The DOE CWG highlights the greater burden of cold-related than heat-related mortality in the United States. The DOE CWG argues that climate change will positively impact overall mortality by reducing cold-related mortality even as heat-related mortality increases with climate change.

A more relevant text on cold-related mortality is the Liu et al. 2025 study that used CDC data to show that annual cold-related age-adjusted mortality rates in the US increased 3.4% (95% CI 2.4% to 4.3%) over the period 1999 to 2022, with a nonsignificant increase from 1999 to 2017, followed by a significant annual increase from 2017 to 2022 of 12.1% (95% CI, 6.3% to 27.1%). In other words, the DOE CWG report selected a period to report during which there was no significant trend in cold-related mortality. See figure below:

Figure. Age-Adjusted Cold-Related Mortality Rates in the US, 1999-2022



Mortality rates were age-adjusted to the US population in 2000. Cold-related mortality rates are plotted as dots, with a Joinpoint model plotted as a line and a single Joinpoint in either 2017 (panel A) or 2016 (panel B).

Image from Liu, M., Patel, V. R., & Wadhera, R. K. (2025). Cold-Related Deaths in the US. *JAMA*, 333(5), 427-429.

Also, this short time series does not support the DOE CWG contention that cold-related mortality is declining with climate change (Comment 1).

Action:

Correct the DOE CWG text to include information on the time series from 1999 to 2022, including that there was a significant 12.1% increase in cold-related mortality over the period 2017 to 2022, which is inconsistent with the argument that cold-related mortality is declining with climate change.

Comment 4

Page 112 states: “Figure 10.2 shows the distribution of results from Gasparini et al. (2015) by country. For the United States the fraction of deaths attributable to temperature was 5.9 percent, of which 5.5 percent was due to cold, thus cold weather killed 14 times as many people as hot weather.”

Comment type: Technical

Figure 10.2 does not consider climate change; these are historic observations over about twenty years, ending about in 2020, depending on the country.

Action:

Include in the DOE CWG report that the figure provides historic context only and does not provide any information or insights into current and future mortality during cold and hot periods in the United States.

Comment 5

Original content:

On pages 111-114, the DOE CWG focused *only* on mortality risk due to temperature extremes, a small component of the health risks due to climate change.

Comment type: Editorial

Heatwaves are associated with stark elevations in not only mortality but also morbidity. This report is missing health and well-being impacts such as the detrimental impacts on older adults, maternal health, changes in food security and malnutrition, changes in the geographic range and seasonality of climate-sensitive infectious diseases, detrimental impacts on mental health

and well-being, increased exposure to air pollution, increased exposure to wildfires and related pollution, and mixed impacts on communicable and non-communicable disease. Other references provide abundant evidence that climate change is worsening health risks by these many pathways globally and in the US (IPCC 2022, Baharav et al. 2023, Jiao et al. 2023, Kuehn et al. 2017, Zhang et al. 2023, Solomon and LaRocque 2019, Boscarino et al. 2014, Obradovich et al. 2018, Zhong et al. 2018, Orru et al. 2017, Hayden et al. 2023, Law et al. 2025). Lacking discussion of these many other health impacts gives the impression that broader conclusions about climate impacts on health are brought into question by the DOE CWG concerns over temperature-related mortality, when in fact the report says nothing about other climate-health pathways.

Action:

To address this concern, the DOE CWG needs to broaden this discussion to include the literature on health impacts of climate change in more ways than heat and cold extremes and their impact on mortality, and to put into context that their criticisms of temperature-related mortality estimates address a small component of the overall health effects of climate change. This at least includes the impacts on older adults, vector borne diseases, maternal health, mental health, well-being, food security and malnutrition, pollution and health, and exposure to wildfires and health.

Comment 6

Original text:

Statement 1, Page 113: “In the context of large declines in heat-related mortality, rising temperatures are associated with a net saving of lives since they reduce mortality from cold events. AR6 Working Group 2 Chapter 16.2.3.5 (O’Neill et al. 2022) acknowledges that heat-related mortality risk is declining over time:

Heat-attributable mortality fractions have declined over time in most countries owing to general improvements in health care systems, increasing prevalence of residential air conditioning, and behavioral changes. These factors, which determine the susceptibility of the population to heat, have predominated over the influence of temperature change.

Yet the IPCC misrepresents the overall situation in its AR6 Synthesis report. Section A.2.5 of that document states: “In all regions increases in extreme heat events have resulted in human mortality and morbidity (very high confidence).” But it is silent on the larger decline of deaths during extreme cold events.”

Comment type: Technical, Reference

While declines in heat-related mortality have been observed in some regions, studies indicate this reduction has not been geographically homogeneous, and in some instances slowed or even reversed (Sheridan et al. 2021). And while population susceptibility to heat has changed, the extent to which and sustainability of individual adaptive capacity remains uncertain in the context of a warming world (Arbuthnott et al. 2016).

The DOE CWG report needs to consider more than the Synthesis report of the IPCC AR6; WGII Chapter 7 has more information on the relative impacts of heat and cold, including:

“Wide ranging knowledge regarding the specific detection of heat- and cold-related mortality/morbidity and its attribution to observed climate change is lacking. Although there has been an observed increase in winter-season temperatures for a number of regions, to date there is variable evidence for a consequential reduction in winter mortality and susceptibility to cold over time due to milder winters; some countries demonstrate decreasing trends, while other countries show stable or even increasing trends in cold-attributable mortality fractions over time (e.g., Arbuthnott et al. (2020); Åström et al. (2013); Diaz et al. (2019); Hajat (2017); Hanigan et al. (2021); Lee et al. (2018b)).”

And

“Some research has found a negative effect of extreme cold on well-being (Yoo et al., 2021); increasing winter temperatures associated with climate change could serve to compensate for the impact of increased summer temperatures. However, the effect of high temperatures is typically found to be stronger than the effect of low temperatures, and in some cases no detrimental impacts of cold weather are found (Almendra et al., 2019; Mullins and White, 2019).”

Furthermore, the DOE CWG states that there is a “larger decline of deaths during extreme cold events”, but this is not backed by any scientific citations. In fact, “a recent health impact projection study in more than 800 cities in Europe showed that a future reduction of cold deaths is unlikely to offset the projected increase in heat deaths.” (Alahmed et al., 2025).

Action:

To address the concerns above, the DOE CWG needs to correct its selective quote of the IPCC, and expand and detail a more holistic impact of heat and cold on human health. The CWG needs to incorporate the results of the research cited here, including work that shows reduction of cold deaths is unlikely to offset projected increase in heat deaths.

Comment 7

Original text:

Statement 2, page 113: “The observed decline in U.S. heat-related mortality has been specifically attributed to adaptation. Wang et al. (2018) exploited the spatial variability of heatwave-related mortality across 209 U.S. cities from 1962 to 2006. While simple correlation appeared to imply an increase in mortality risk during heatwaves, accounting for adaptation to heatwave intensity caused the effect to fall to near zero and become statistically insignificant. They used the results of their epidemiological model to project heat-related mortality out to 2050 under four RCP warming scenarios (including RCP8.5) with and without adaptive behavior. Assuming people continue to adapt to the heatwave risks in the regions in which they live, Wang et al. (2018) project not only no increase in heat-related mortality, but an overall mortality decrease for the U.S. They conclude that ignoring adaptation would result in a substantial overestimate of future mortality related to heat waves... Accounting for adaptation, the overall heat-related mortality by 2050 would not change substantially over time compared to 2006.”

Comment type: Technical, Reference

This is a selective decision to not include the followup sentence on this statement that says:

“Ignoring adaptation in projections would result in a substantial overestimate of the projected heat wave-related mortality (by 277–747% in 2050). Incorporating the empirically estimated adaptation into projections would result in little change in the projected heat wave-related mortality between 2006 and 2050. **This differs regionally, however, with increasing mortality over time for cities in the southern and western U.S. but decreasing mortality over time for the north.**”

With the part that was left out of the text in bold. This work does not show a uniform decrease in mortality, but rather that it is location dependent, due to, in part, the saturation and use of air conditioning. This work shows that there is a saturation level for adaptation— places already saturated with air conditioning see increases in mortality because they cannot adapt out of the impacts from heat, providing a limit to adaptation. Furthermore, this work only uses temperature related heat, while the most up to date literature emphasizes the inclusion of humidity (Baldwin et al. 2023; Vecellio et al. 2023; Buzan and Huber 2020). As the atmosphere warms, evaporation of water increases, leading to higher humidity across much of the globe,

modifying the impact of humidity on the heat-health relationship. See Figure 3, below, from their work that clearly shows increases in mortality throughout multiple regions in the United States, particularly in regions such as the Northwest, Southwest, West, where population growth is expected in the future (Cooper Center). With increases in the frequency and intensity of heat, mortality can still be identified in hot periods, irrespective of season or geography.

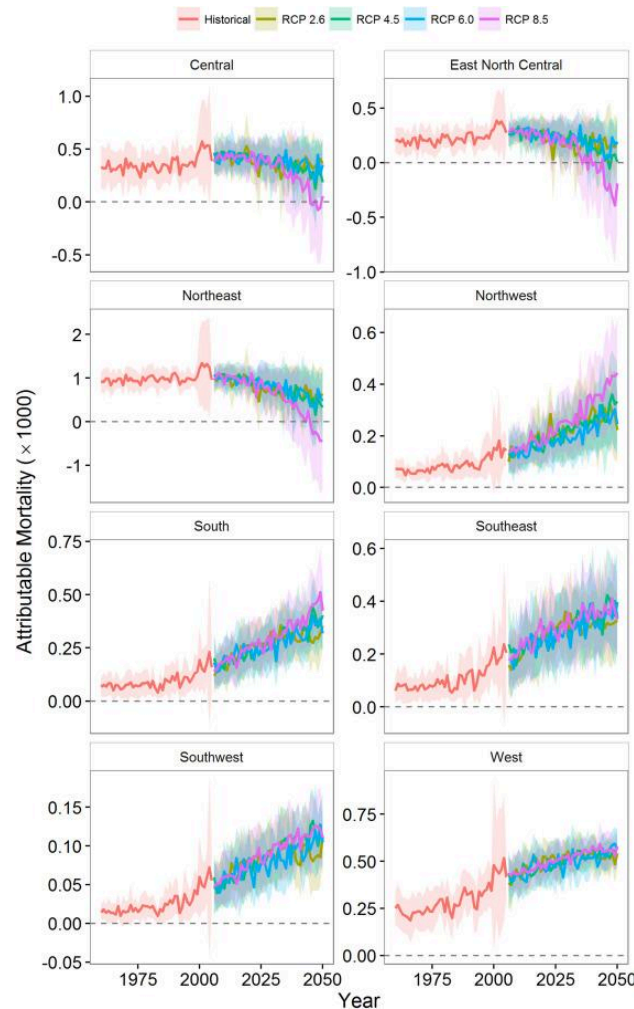


Figure from Wang, Y., Nordio, F., Nairn, J., Zanobetti, A., & Schwartz, J. D. (2018). Accounting for adaptation and intensity in projecting heat wave-related mortality. *Environmental research*, 161, 464-471. "Fig. 3. Projected mortality attributable to heat waves in 1960–2050 under historical, RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 scenarios in each of the eight climate regions: a. Northeast, b. Central, c. East North Central, d. Northwest, e. South, f. Southeast, g. Southwest, and h. West. The models considered adaptation but ignored intensity (Model 3). The solid lines and the shaded areas represent mean $\pm$ standard deviation across the predicted values using all climate models."

Action:

To address this issue, the DOE CWG needs to correct its selective quote of the article, and address the spatial heterogeneity in the mortality outcomes from the work cited, as is shown in the figures attached.

Comment 8

Original text:

Statement 3, page 112: “There is strong evidence that people adapt to weather risks. Lee and Dessler (2023) reported that 86 percent of temperature-related deaths across 40 cities in the U.S. were due to cold-related mortality, and that due to adaptation the relative risk of death declined in hot and cold cities alike as seasonal temperatures increased. Allen and Sheridan (2018) found that short, early-season cold events were 2 to 5 times deadlier than hot events, but the mortality risk of both cold and hot extremes drops to nearly zero if the events occur late in the season.”

Comment type: Technical, References

While people may adapt to weather risks, questions remain as to the capacity to adapt. Populations without access to air conditioning or individuals with chronic illness differ in personal adaptive capacity. Population health is not the same as individual health. The above reference misrepresents the methodological approaches and conclusions of Allen and Sheridan (2018) as no direct comparison between heat and cold events was conducted. There is some evidence that extreme temperature events in the early season have a disproportionately large human impact compared to those later in the season (Anderson and Bell 2011; Ng et al. 2014), with one suggested reason being a lack of acclimatization. However, to claim thermal risk becomes near zero later in the season — as heatwaves become longer-lasting — is inaccurate.

Action:

To address these concerns, the DOE CWG needs to correct the misrepresentation of the Allen and Sheridan (2018) work. It also needs to include information about the capacity and limitations to both population- and individual-scale adaptation

10.3.2 Mortality risks and energy costs

Comment 1

Original text:

Statement 1, page 114 “On very hot days ($>30^{\circ}\text{C}$) electricity spending in high-income households rises by 0.5 percent but does not change at all in low-income households. The latter result is observed even in subsamples where all households have AC. Cong et al. (2022) report similar findings for a sample of households in Arizona. The implication is that even with widespread adoption of home heating and cooling systems, inability to afford energy leaves low-income households exposed to weather extremes.”

Comment Type: Technical, Editorial

The statements made here, which are that “an inability to afford energy leaves low-income households exposed to weather extremes” should clearly be used in reference back to the former section (10.3.1), specifically the citation of Wang et al. (2018), which assesses the impact of adaptation on heat and cold related mortalities. As the authors suggest here, if adaptation is unaffordable due to high energy costs, then we can look at the outcome from Wang’s work for the impact of heat on mortalities without adaptation (see Figure 2a below), which shows a U.S. mean increase in attributable mortalities. Wang et al. (2018) do not provide a regional breakdown (otherwise we would show that here).

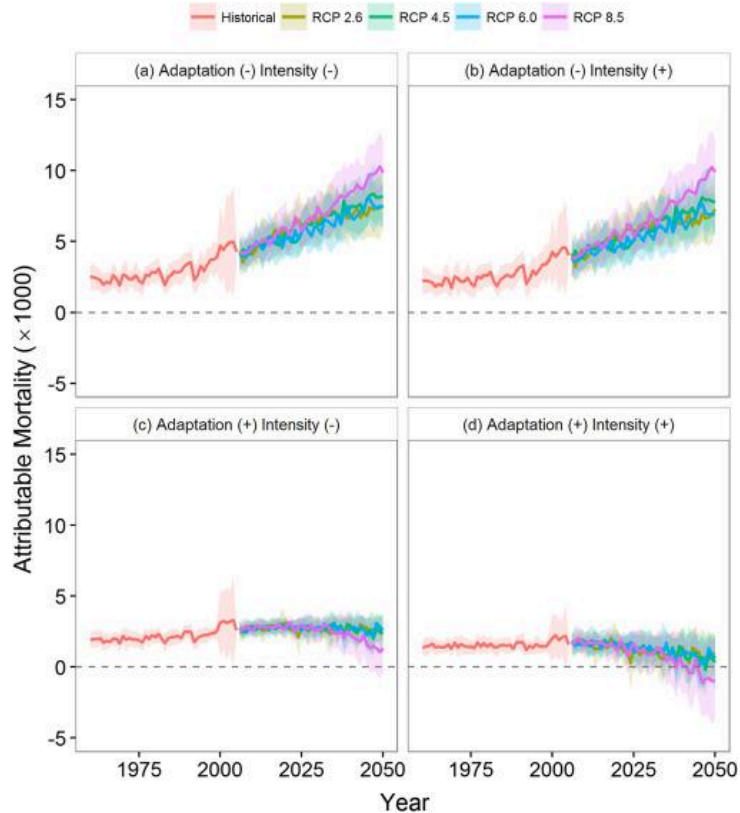


Figure from Wang, Y., Nordio, F., Nairn, J., Zanobetti, A., & Schwartz, J. D. (2018). Accounting for adaptation and intensity in projecting heat wave-related mortality. *Environmental research*, 161, 464-471. "Fig. 2. Projected mortality attributable to heat waves in 1960–2050 under historical, RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 scenario. a. Model 1: neither adaptation nor intensity was considered; b. Model 2: adaptation was considered but intensity was ignored; c. Model 3: intensity was considered but adaptation was ignored; d. Model 4: both adaptation and intensity were considered. The solid lines and the shaded areas represent mean $\pm$ standard deviation across the predicted values using all climate models."

If the authors are going to cite the inability for populations to adapt due to the cost of adaptation, they need to take that into consideration when claiming that populations will adapt to a changing climate. This section is a contradiction to the arguments these authors made in 10.3.1, and to fix this the authors need to incorporate the potential inability to adapt due to financial circumstances into their assessment in 10.3.1.

Action:

In order to address our concerns here, the DOE CWG needs to include these conclusions that adaptation may be cost-prohibitive into their logic and argument in section 10.3.1 that people

can completely adapt their way out of a changing climate. Additionally, including evidence of the limitations on capacity to adapt is needed.

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Section 10.3: Mortality from Extreme Temperatures

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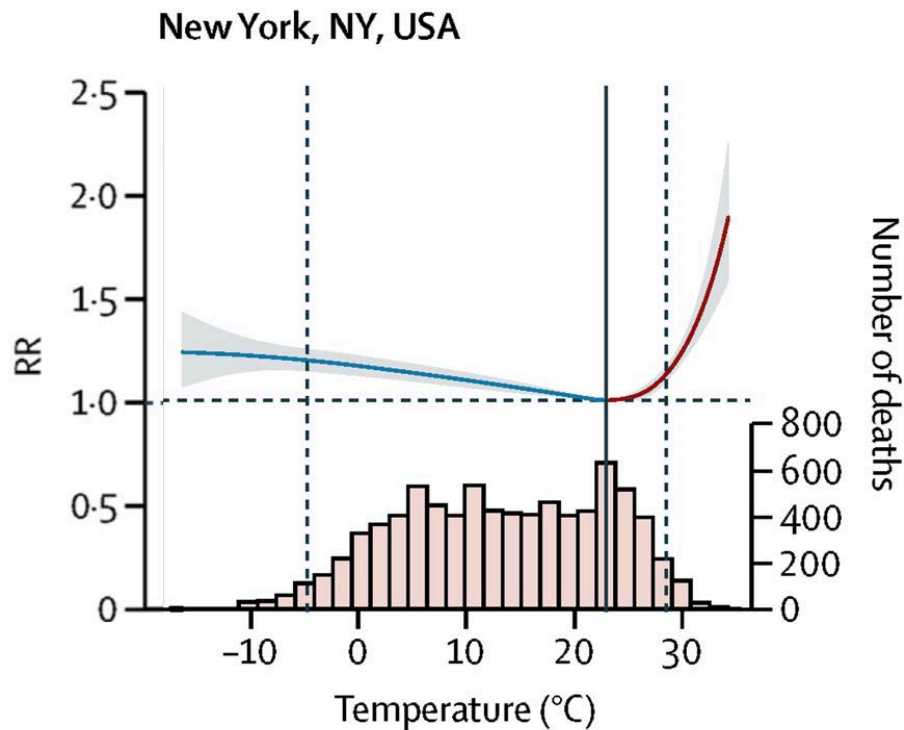
Technical Comment on Section 10.3.1, Heat and Cold Risks (pp. 111-113)

Error: The document's focus on mortality from extreme heat neglects the substantial burden of nonfatal health impacts, such as heat exhaustion, kidney disease, and cardiovascular strain. As Flouris et al. (2018) note, "Occupational heat strain (i.e., the effect of environmental heat stress on the body) directly threatens workers' ability to live healthy and productive lives." The literature connects heat exposure to increased risks of kidney disease (Flouris et al., 2018; Johnson et al., 2019), cardiovascular disease (Liu et al., 2022), as well as an expanding range of vector-borne diseases (Rocklöv & Dubrow, 2020).

Recommended Fix: Expand the assessment of health impacts to include morbidity and nonfatal outcomes, referencing comprehensive sources such as the Lancet Countdown (Romanello et al., 2024), to present a fuller picture of climate-related health risks.

Geographic Disparities in Temperature-Mortality Relationships

Error: While the document recognizes the U-shaped relationship between temperature and mortality, it under-represents both the asymmetry of this curve and the geographic differences. The increase in mortality associated with increasing temperatures is generally more pronounced than that associated with cold:



Adapted from Fig. 1 of Gasparrini et al. (2015).

In this example, slight warming in New York may initially reduce cold-related deaths, but with enough warming, the rise in heat-related deaths overtakes these gains, resulting in net increases in mortality. For the U.S. overall, warming up to $\sim 3^{\circ}\text{C}$ roughly balances heat- and cold-related deaths, yet beyond that threshold, heat mortality rises sharply (Lee & Dessler, 2023) unless there is significant adaptation, which is uncertain (see comment below).

Recommended Fix: Provide geographically detailed temperature-mortality analyses, clarifying how net mortality shifts with warming in different regions. Indicate thresholds (e.g., at $\sim 3^{\circ}\text{C}$ above preindustrial levels) at which heat-related deaths begin to outweigh reductions in cold-related mortality, and explicitly note that less-adapted populations face fewer potential benefits and greater risks.

Technical Comment on Section 10.3.1, Mortality Risks and Energy Costs (pp. 113-114)

Error: Emphasizing air conditioning (AC) as the primary adaptation to heat overlooks important practical limitations. Millions of outdoor workers (e.g., in agriculture, construction, and delivery services) cannot rely on AC for protection. Additionally,

installing and operating AC systems in places where it was previously unnecessary involves significant capital and electricity costs, which are especially burdensome for economically vulnerable populations. Dessler (2025) estimated that climate change increased annual electricity costs by \$80 per person in Texas in 2023 (compared to a mid-20th century climate), reflecting the need for increased air conditioning (Dessler, 2025).

Given the track record of our society, adaptation seems like a bad bet. For example, a bill to air condition prisons in Texas failed in the Texas Legislature this year, continuing a 20-year string of failure. There is no clearer place where adaptation needs to occur, yet the failure year after year suggests that those with money just don't want to spend it helping the poor adapt.

Another example is the Low Income Home Energy Assistance Program (LIHEAP), which has historically helped vulnerable households maintain safe indoor temperatures. However, the current administration has moved to eliminate LIHEAP, firing program staff in April 2025 and proposing zero funding for 2026. Such policies directly undermine the DOE document's core assumption that continued adaptation is a certainty that will prevent mortality increases.

Recommended Fix: More realistically assess adaptation strategies by discussing the economic and institutional barriers to widespread AC deployment, and acknowledge populations (e.g., outdoor workers) for whom this strategy is not feasible.

Technical Comment on Section 10.3.2, Energy Source Costs

Error: The unstated assumption that fossil fuels must be relied upon to provide cheap electricity for AC is outdated. Renewables, such as wind and solar, now often provide the lowest-cost electricity. Focusing exclusively on "net zero" scenarios misses the opportunity to explore a range of economically and technically viable pathways to decarbonization.

Recommended Fix: Review and present up-to-date research on the costs of decarbonizing the energy sector, including multiple decarbonization levels (e.g., 60%, 75%, 90%, and 100%) rather than solely net-zero scenarios. Clarify that maximizing affordable, climate-safe renewable energy supports both adaptation and mitigation goals.

Conclusion

This section, which argues that extreme heat is not a significant health concern, rests on several important errors:

- It ignores health impacts other than death from extreme temperatures. An enormous amount of research has connected climate change to human health impacts and this needs to be reviewed.
- Their analysis of mortality glosses over the fact that the balance between lives saved and lives lost depends on how much warming occurs and what region you are testing. With small amounts of warming, some regions will win and others will lose. As warming increases, fewer places win and more lose until, with enough warming, everyone is a loser. The revised document needs to flesh out these details.
- The reliance on adaptation is a dangerous delusion. It conveniently ignores millions of outdoor workers and the prohibitive capital and energy costs for the economically vulnerable. Even in the U.S., the current administration is cutting funding that could be used to help people adapt.
- Regardless of anything else, we do need to enhance access to air conditioning. This requires producing electricity at the lowest cost, which means we should be building as much wind and solar as possible.

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A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate: A Response to Chapter 11

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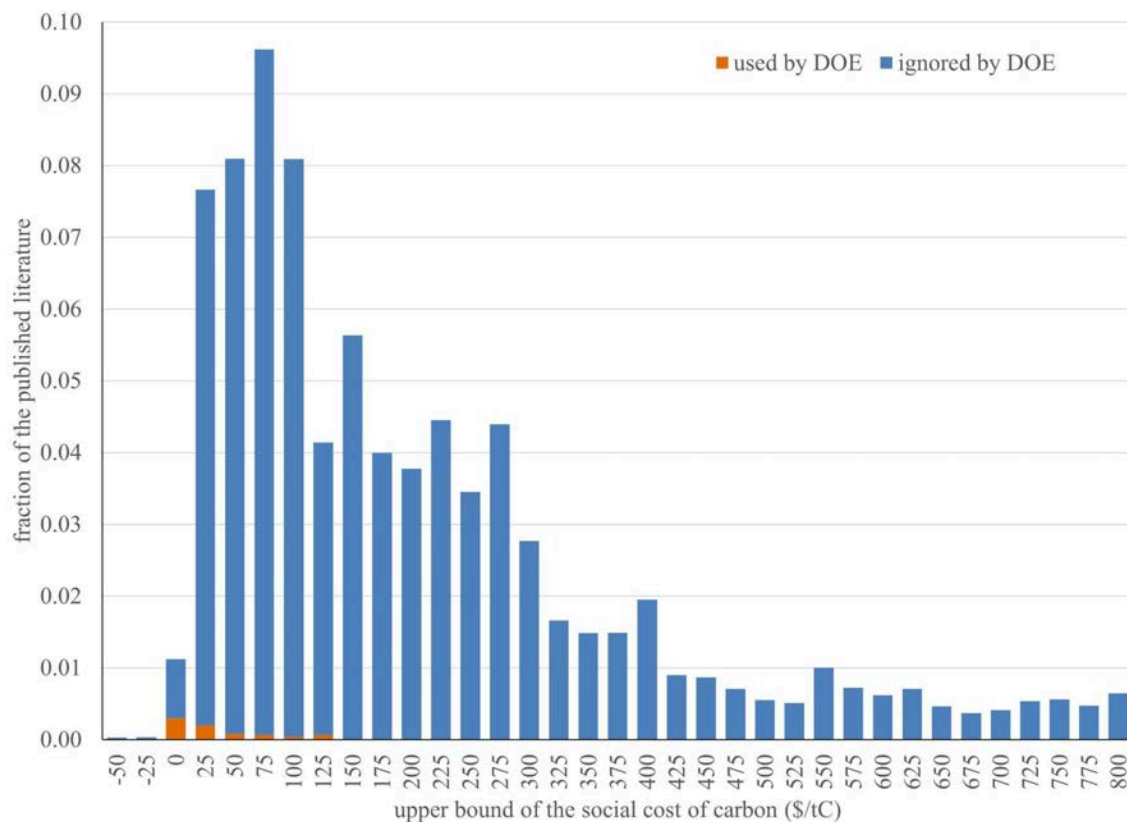
Overall assessment

This part of the response is a **technical** comment on Chapter 11 of the DOE CWG report (pp. 116–128). Before raising particular points about particular sections and paragraphs, we start with an overall assessment of Chapter 11.

Chapter 11 tries to argue that the risks of climate change to the U.S. economy are so small that almost no greenhouse gas emission reduction measures pass a cost-benefit test. The authors misrepresent the economic literature through selective citation and frequent miscitation, examples of which we describe below. However, the authors fail in what appears to be their mission: They conclude that climate change is likely to reduce economic output and welfare in the U.S.

Chapter 11 has several key omissions.

First, the authors ignore the risks and uncertainties about climate change and its impacts (Weitzman 2009; Nordhaus 2013; Berger, Emmerling, and Tavoni 2017; Gillingham et al. 2018; Y. Cai and Lontzek 2019; Barnett, Brock, and Hansen 2020; van den Bremer and van der Ploeg 2021; Lemoine 2021; Traeger 2023). They focus not so much on the central part of the distribution of possible outcomes, but zoom in on its left tail where everything turns out better than most analysts expect let alone fear (e.g., Figure 1). A long history of work on risk management points to the importance of considering the full distribution of outcomes, including tail risks (e.g., Heal and Millner 2014; Barnett, Brock, and Hansen 2020). The authors' general approach would also argue against the purchase of insurance, the maintenance of a standing army in peacetime, and many other regularly accepted precautionary measures (Weitzman 2012).



Estimates are classed into intervals of \$25/tC; the number on the horizontal axis is the upper bound of that interval; for example, the estimate marked “0” denotes estimates between -\$25/tC and \$0/tC. Estimates are for emissions in 2025 and given in 2024 U.S. dollar per metric tonne of carbon. Estimates are quality-weighted and censored as in Tol (2023). Data are from Tol (2024b).

Second, the authors limit their attention to the U.S., but do not defend their position. They ignore the implications of a breakdown of global cooperation on climate policy, they do not discuss the legal (Kuhn 1938) and moral (Kelleher 2025) implications of ignoring impacts outside the U.S.A., and they steer clear of the impacts of climate change on international trade (Brown et al. 2017; Baldos, Hertel, and Moore 2019; Dallman 2019), investment (Klusak et al. 2023), and migration (R. Cai et al. 2016; Mahajan and Yang 2020; Burzynski et al. 2022). As the National Academies (2017) noted, estimates of the domestic costs of climate change “need to consider the potential implications of climate impacts on, and actions by, other countries, which also have impacts on the United States.”

The chapter also contains numerous errors and misrepresentations, as detailed in the comments below.

To correct the issues describe in this critique, the DOE CWG should:

- Evaluate the full distribution of the economic impacts of climate change, including the potential for significant downside risk and the role of precautionary measures.
- Summarize the full peer-reviewed literature on the national and subnational economic impacts of average and extreme weather.
- Incorporate a complete range of the literature's estimates of the SCC, including by following the recommendations of the National Academies (2017) when evaluating the diverse approaches to SCC calculations.
- Appropriately distinguish between unknown likelihood, high-impact outcomes and high impact outcomes known to be of low likelihood, and incorporate literature on decision-making under deep uncertainty when evaluating the impacts and implications of climate tipping points.
- Correct other misrepresentations identified in this critique.

Climate Change and Economic Growth

This section of the comment is a **technical** comment on section 11.1 of the DOE CWG report (pp. 116–120).

This section of the DOE CWG report discusses the impact of climate change on economic growth, arguing that “CO₂-induced warming might have some negative economic effects but they are too small to justify aggressive abatement policy.” In making this argument, the CWG misrepresents the literature. For example:

- The DOE CWG writes:

Mohaddes et al. (2023) found that warm weather shocks have small negative effects on U.S. state-level output but not income, while cold weather shocks negatively affect both and the impacts are about four times larger, implying a shift to warmer conditions would, if anything, yield a net economic benefit for the U.S. (p. 117)

In fact, Mohaddes et al. (2023) find that warm weather shocks have a significantly negative impact of unusually hot weather on income per capita in the last 33 years of the sample (1983–2016), but not in the whole sample (1963–2016). They find a negative impact on total output in the whole sample. This may mean that migration offset the economic impact before 1983 but not after. This study suggests that the U.S. economy has become more vulnerable to hot weather. The DOE's ‘net benefit’ would be

smaller if weather variability increased. The DOE ignores that Mohaddes et al. (2023) also finds significant impacts of precipitation shocks.

- The DOE CWG writes:

economists have long been reluctant to endorse attempts to “stop” climate change or even aggressively reduce GHG emissions because the costs would not be worth it (p.117)

This twists a key message in the literature. Since Nordhaus (1982), economists have consistently argued for greenhouse gas emission reduction. See, for example, Akerlof et al. (2019), calling for a robust, gradually rising carbon tax-and-dividend system; the original signatories of this statement included 28 Nobel Memorial Prize laureates, 4 former Federal Reserve chairs, and 15 former Council of Economic Advisers chairs.

- The DOE CWG writes:

[t]he Optimal Policy scenario [of Nordhaus (2018)] barely deviates from the business-as-usual path. (p.118)

This is a misrepresentation of the emissions trajectories shown in Figure 2 of Nordhaus (2018). Global fossil fuel CO₂ emissions in Nordhaus (2018)’s baseline scenario grow from about 35 Gt in 2015 to nearly 60 Gt in 2050 and over 70 Gt in 2100. Emissions in Nordhaus (2018)’s Optimal Policy scenario peak in 2045 at 40 Gt and decline by 2100 to about 15 Gt. DOE correctly notes that Nordhaus (2018) projects 3.5°C warming in his Optimal Policy scenario, but this reflects limitations of Nordhaus (2018)’s physical model. The calculated Optimal Policy CO₂ trajectory resembles that of the SSP2-4.5 emissions pathway, which has a median warming based on IPCC AR6 of about 2.7°C in 2100.

DOE dismisses without proper citation or substantive discussion the most recent version of Nordhaus’s DICE model, DICE-2023 (Barrage and Nordhaus 2023) (p. 119). DICE-2023 includes a more realistic representation of the coupled climate and carbon cycle (following the guidance of the National Academies (2017)), as well as allowing for abatement of land use CO₂ emissions and non-CO₂ emissions. This improved physical representation leads to substantially more realistic temperature outcomes. For example, in DICE-2023, limiting warming to below 2°C requires net-zero CO₂ emissions by 2100; by contrast, Nordhaus (2018) erroneously calculated that limiting warming to 2.5°C would require zero fossil emissions by 2040.

- The DOE CWG writes:

Greßer et al. (2021) developed a regional economic data set for 1,542 sub-national regions around the world between 2005 and 2015 and found temperature had no effect on growth. (p. 119)

Gresser, Meierrieks, and Stadelmann (2021) do not study the impact of climate on growth. They study its impact on output. DOE do not cite Callahan and Mankin (2022), Damania, Desbureaux, and Zaveri (2020), Kalkuhl and Wenz (2020), Kotz et al. (2021), Kotz et al. (2022) and Kotz et al. (2024) who use subnational data and find significant effects of weather on economic growth.

- Referring to Newell, Prest, and Sexton (2021), the DOE CWG writes:

the net effect is likely positive but too uncertain to distinguish from zero (p. 119)

Figure 6 in Newell, Prest, and Sexton (2021) reveals that this holds for their “growth” models but not for their “level” models, which show a loss of several percent of GDP at the end of the century. Newell, Prest, and Sexton (2021) show that level models are more likely to cross-validate than growth models. DOE thus highlight the results of the poorly performing models and suppress the findings from the models with better forecast skill.

- The DOE CWG cites Berg, Curtis, and Mark (2023), a working paper subsequently published as Berg, Curtis, and Mark (2024).

Regressing country-level GDP on global-mean temperature, as Berg, Curtis, and Mark (2024) do, is a fairly novel methodological choice that demands close scrutiny. Nonetheless, a key finding of this study is that “Richer countries, in particular, such as the United States, tend to experience negative impulse responses of real GDP per capita growth to increases in global temperature.”

- The DOE CWG writes:

An influential study in 2012 [(Dell, Jones, and Olken 2012)] suggested that global warming would harm growth in poor countries but the finding has subsequently been found not to be robust (Tol 2024). Studies that take full account of modeling uncertainties either find no evidence of a negative effect on global growth from CO2 emissions or find poor countries as likely to benefit from it as rich countries. (p. 120)

Tol (2024a) pools the estimated coefficients from eight growth models. The pooled estimate is very close to Dell, Jones, and Olken (2012), which thus appears to be the most robust in the published literature.

Tol (2024a), the only cited study in this paragraph, finds a negative effect of climate change on economic growth. He also finds that the impact is larger in poorer countries, a result that goes back to Schelling (1992), who provided the opening quote in this section of the DOE CWG report, and indeed further Albala-Bertrand (1993; Blaikie et al. 2003; Kahn 2005).

This section in the DOE CWG report ends with a partial reproduction of a graph from CEA and OMB (2023). The reproduced graph does not include the legend or caption, making it challenging to interpret without referring to the original. The graph shows consistently negative impacts of additional climate change on the US economy across twelve peer-reviewed studies. Four of these studies use the econometric methods that are the subject of the DOE CWG report. Impact studies using other methods, the majority of the studies in CEA and OMB (2023) and indeed the literature, are ignored by the DOE CWG report. The DOE trivializes the negative impacts as “a few percent” and “negligible”. As a reference, a one percent loss of GDP in 2025 would be a cost of about \$300 billion; “a few percent” could equally well be phrased as “more than a trillion dollars” (relative to today’s economy). Further, referring to the economic impacts of climate change as “negligible” directly contradicts the text of the CEA-OMB report, which states that “[c]limate change presents many economic, financial, and fiscal risks across the United States,” and that “[e]ven under the low global emissions scenario, the consequences of physical climate damages for the macroeconomy weaken the fiscal outlook” (CEA and OMB 2023).

Models of the Social Cost of Carbon

This section of our comment is a **technical** comment on section 11.2.1–11.2.2 of the DOE CWG report (pp. 120–122).

This section of the DOE’s report discusses the estimation of the social cost of carbon (SCC), or the net present value of the monetized welfare loss associated with an additional ton of CO₂ emitted. The first few paragraphs of this section do correctly summarize various methods used to estimate the SCC. However, the overall conclusions of the report are out of step with the consensus of the literature on the SCC. For example, the National Academies undertook an extensive study of

approaches used to estimate the SCC (National Academies 2017), prompting multiple research teams to engage in multi-year efforts to update the SCC with new damage functions, socioeconomic scenarios, climate modeling, and approaches to risk and discounting (EPA, 2023). Further, multiple recent meta-analyses have synthesized the state of the literature on the SCC, yielding consensus values far higher than the DOE CWG's perspective. Tol (2023) showed that SCC estimates have risen over time, and Moore et al. (2024) showed that experts judge the true SCC to be even higher than recent government updates, approximately \$283 tCO₂⁻¹ when combining expert judgement with published estimates. These syntheses of the literature account for the myriad potential variations in SCC estimates, and yet are not discussed by the DOE CWG report.

Additionally, the authors take it as given that the appropriate discount rate is high. They do not defend this position, which is at odds with the view of many economists (Weitzman 2001; Freeman and Groom 2015; Drupp et al. 2018; Bauer and Rudebusch 2023; Nesje et al. 2023).

Many of the other parts of this chapter rely on critiques of mainstream equilibrium climate sensitivity (ECS) estimates and on revised estimates of the agricultural impacts of global warming. These critiques are discussed in more detail in Chapters 4 and 9 of the DOE CWG report, respectively, and we refer the reader to the corresponding sections of this reply.

This section also contains a variety of errors.

- Some errors suggest carelessness. For example, the DOE CWG writes

in DICE only three were needed and were originally chosen to assign a predetermined penalty (1.2%) to global output as of 3 warming

In fact, Nordhaus (1992) assumed 1.33%.

- Other errors suggest misunderstanding of how IAMs are calibrated. For example, the DOE CWG writes

Every IAM assumes a value of the Equilibrium Climate Sensitivity (ECS), which controls the amount of warming that results from CO2 emissions and can be freely varied for the purpose of generating a distribution of SCC values associated with uncertainties over ECS. But as Roe and Baumann (2013) pointed out, time-to-equilibrium increases with the square of ECS, so an upward

adjustment of the ECS parameter without an appropriate slowing down of the adjustment process can yield distorted present value damage estimates. (p. 121)

This paragraph asserts that parameters in IAMs are singly rather than jointly calibrated. No evidence is provided. Specifically, following the recommendations of the National Academies (2017), the most recent U.S.-government-endorsed updates to the SCC (EPA, 2023) embed reduced-complexity climate models into their IAMs, which numerically integrate the climate response to CO₂ perturbations accounting for deep-ocean adjustment times similar to the recommendations by Roe and Bauman (2013). They do not simply specify an ECS value.

- The section also makes assertions regarding the content of the EPA SCC's report that do not correspond to the report. The DOE CWG writes

For example, in 2023 the U.S. Environmental Protection Agency raised its preferred SCC value about 5-fold over the estimates it had issued ten years earlier. This is not because new data had been collected or better mathematical methods had been invented, but because new assumptions had been used, and the validity of those assumptions was a separate question. Tabulations on EPA (2023) p. 81 show that if assumptions similar to earlier analyses had been applied, the results would not have materially differed from before. (p. 122)

No such table appears in the EPA (2023) report. The table on page 81, as cited by DOE, disaggregates the SCC into categories of damages (e.g., agriculture vs. sea level rise) but makes no claim about assumptions relative to earlier analyses. Further, no other table in the EPA SCC update makes such a claim. Indeed, Table 5.1 of EPA (2023) shows a range of updates made by the EPA in their SCC estimation that go beyond “new assumptions”, including new probabilistic socioeconomic scenarios, new carbon-climate modeling, and updated sectoral damage functions based on peer-reviewed literature.

The distribution of social cost of carbon estimates

This section of our comment is a **technical** comment on section 11.2.3 of the DOE CWG report (“Evidence for low SCC,” p. 123).

- The DOE CWG present an unbalanced overview of the distribution of SCC estimates. The DOE CWG writes

Dayaratna et al. (2023) used the updated empirical ECS distribution estimate of Lewis (2022), which assimilates modern instrumental and paleoclimatic temperature records, and allowed for a 30 percent gain in the CO2 fertilization benefit in the FUND model, and found that, even at a low discount rate of 2.5 percent, the median SCC as of 2050 is only \$18.67, with a 24 percent probability of the true value being negative. At a five percent discount rate the median SCC value is negative until the mid-2040s and at 2050 was only \$0.37 with a 49 percent probability of being negative. Thus, under reasonable assumptions a mainstream IAM using updated scientific inputs yields evidence consistent with the SCC not being significantly greater than zero. (p. 123)

Dayaratna and McKittrick (2023) find a mix of social costs and social benefits of carbon, depending on the discount rate used, the assumed distribution of the climate sensitivity, and the assumptions on the strength of CO2 fertilization. DOE omits the social cost, even though the average social cost of carbon in Dayaratna, McKittrick, and Kreutzer (2017), Dayaratna, McKittrick, and Michaels (2020), and K. D. Dayaratna and McKittrick (2023) is a positive \$24/tC.

Using FUND, the same model as Dayaratna and McKittrick (2023), Anthoff, Tol, and Yohe (2009) similarly found that CO2 fertilization may — in the near term, for certain parameter values, and considering only the impacts represented in FUND — offset the negative impacts of a marginal increase in climate change. They noted, however, that this effect is less important in developed economies such as the U.S.A., and moreover disappears when parameter uncertainty is accounted for. Anthoff, Tol, and Yohe (2009) further did not benefit from the last 16 years of modeling and empirical studies of climate change impacts on agriculture, discussed elsewhere in this review, as well as subsequent studies on other major impacts like mortality. DOE does not refer to Anthoff, Tol, and Yohe (2009), even though it directly contradicts its conclusions.

Where Dayaratna, McKittrick, and Kreutzer (2017) and Dayaratna, McKittrick, and Michaels (2020) use the mean social cost of carbon, Dayaratna and McKittrick (2023) use the median. The distribution is right-skewed, so the median is smaller than the mean. The latter is the appropriate statistic, as the SCC should represent the expected (i.e., mean) welfare change in response to a marginal emission.

Figure 1 compares the histogram of estimates of the social cost of carbon by Dayaratna and colleagues to the wider literature. DOE emphasizes a small and unrepresentative part of the literature.

- In arguing that the SCC should be balanced against the private marginal benefits of fossil fuel use, the DOE CWG writes

Tol (2017) estimates that the private benefit of carbon is large relative to the social cost. (p. 123)

Tol (2017) was peer-reviewed and rejected because it compares the average private benefit to the marginal social cost. DOE faithfully reproduces this error.

Tipping Points

This section of our comment is a **technical** comment on section 11.2.4 of the DOE CWG report (pp. 123–125).

The DOE CWG report presents a confused interpretation of tipping points and nonlinear behaviour in the climate system. The authors attempt to draw a distinction between abrupt changes instigated by forcing and the existence of bifurcations/bistability in a natural system. This distinction is erroneous. An abrupt transition, whether or not it is initiated by forcing or natural variability, is indicative of a system's bistability (Ashwin et al., 2013). A system that responds linearly to applied forcing (as in the case of summer Arctic sea ice cover) is not considered to exhibit tipping behaviour either by the IPCC (see below) or by the wider scientific community.

The author's errors here may be unintentional, as there is considerable diversity in the use of the phrase "tipping point" in the literature (Kopp et al., 2025). However, the DOE CWG leverages this ambiguity to make more stark and consequential errors in their subsequent discussion.

The authors imply in particular (p124) that because bifurcations are a "natural" feature of the climate system, an abrupt transition between states would be just as likely under small perturbations as they would be under forcing. They use this framing to suggest that such transitions may occur irrespective of the forcing and could be inherently unpredictable. This framing is misleading, and is inconsistent with the published literature (Ashwin et al., 2013; Dijkstra and Ghil, 2005; Chapman et al., 2025). While systems can "tip" through small perturbations (noise), the *likelihood* of their tipping is increased by forcing (when the forcing is acting to move the system towards its bifurcation point). It is for this reason that possible 'tipping points' in the climate system (such as the Atlantic Meridional Overturning Circulation, AMOC) are generally

considered *both* challenging to predict *and* plausibly more likely to occur under (GHG) forcing. This is a point that the authors seem to intentionally obfuscate.

The further assertion (p124) that "AR6 (WGI, Chapter 1) focuses mainly on the first type of tipping point" is incorrect both for the reason noted above (there is no real distinction between the first and second "types" of tipping) and from the IPCC's own definition: (Chen et al., 2021):

"In some cases, abrupt change occurs because the system state actually becomes unstable, such that the subsequent rate of change is independent of the forcing. We refer to this class of abrupt change as a 'tipping point', defined as a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly"

A system evolving "independent of the forcing" to be "reorganized" is a nonlinear transition between stable states, i.e. a bifurcation. Indeed, prominently consequential --- and most widely considered --- tipping points (e.g. AMOC, Greenland and West Antarctic Ice Sheets) are classic examples of system bistability and bifurcations. In these systems there are suspected but poorly quantified feedbacks that accelerate changes as they emerge (e.g. salinity feedbacks in the AMOC, and marine ice sheet instability in West Antarctica), meaning that the systems can transition abruptly between quasi-steady states (an on-off state of the AMOC, a marine-terminating or land based ice sheet) with distinct timescales for reversal.

The statement that "there seems to be very little to discriminate between a tipping event and natural climate variability" is false. It is helpful here to discriminate between the variability that a system exhibits on some timescale of interest (sometimes called intrinsic or natural variability; e.g., ENSO for interannual timescales) and the *possibility* of a system – through its inherent or natural dynamics – to exhibit much more significant and sustained changes on a comparable timescale. The occurrence of such an abrupt change/tipping event is widely disambiguated from "natural climate variability" as being (a) much larger in magnitude than the intrinsic variability that occurs on comparable timescales and (b) sustained on timescales longer than that of the intrinsic variability. For example, while the AMOC varies by $\pm 30\%$ from year to year (intrinsic variability; McCarthy et al., 2025), a characteristic tipping event could see it decline by 70-100% and remain at this low level for decades (van Westen et al., 2024). Consistent with the rest of the section, the authors confuse a system's chaotic behaviour with its bistability; and obfuscate the meaning of the term "natural climate variability".

Below, we refute many of the more specific claims of the DOE CWG report, particularly in their assertions about the conclusions and assigned uncertainties in the IPCC AR6.

The DOE CWG writes:

Natural climate variability has in the past produced shifts in the West African and Indian monsoons, Amazon forest and coral reef dieback, and disintegration of parts of the Greenland and West Antarctic ice sheets. These impacts can reverse on the decadal and century timescales associated with natural climate variability and ecosystem responses. (p. 124)

While monsoonal shifts can indeed occur on decadal timescales, ice sheets take many millennia to regrow. Changes in the polar ice sheets triggered by human-caused warming will not rapidly be reversed.

Regarding the Atlantic Meridional Overturning Circulation (AMOC) and the West Antarctic Ice Sheet (WAIS) in particular, the DOE CWG quotes selectively from the IPCC AR6 Summary for Policy Makers to support the statement that “the IPCC assigns low probabilities to most, including the largest ones” (p. 125).

In fact, regarding AMOC and WAIS, AR6 concludes that the likelihood of collapse is poorly known, not that it is known to be low. This situation is quite distinct from that of a “large meteor strike” (p. 124), where the statistics of objects that might collide with the Earth can be measured and thus the likelihood of a large strike objectively determined. A better analogy would be the possibility of a world war, about which different experts may have fundamentally different mental models and consequently different assessments of likelihood.

DOE is perhaps confused by the IPCC’s description of rapid ice sheet loss as a “low-likelihood, high-impact outcome.” This results from a confusing definition of the phrase “low-likelihood, high-impact”, as flagged in Kopp et al. (2023) and Lempert et al. (2024). IPCC (2021) writes: “Low-likelihood, high-impact” outcomes are defined as outcomes “whose probability of occurrence is low or *not well known (as in the context of deep uncertainty)* but whose potential impacts on society and ecosystems could be high.” (Emphasis added)

Regarding AMOC, AR6 (Fox-Kemper et al. 2021) notes: “None of the CMIP6 models features an abrupt AMOC collapse in the 21st century, but they neglect meltwater release from the Greenland Ice Sheet. Also, a recent process study reveals that a collapse of AMOC can be induced, even by small-amplitude changes in freshwater

forcing (Lohmann and Ditlevsen, 2021). As a result, we change the assessment of an abrupt collapse before 2100 to *medium confidence* that it will not occur.”

Note that AR6 does not say that AMOC collapse *in general* is of low likelihood, but that there is *medium confidence* (in IPCC terminology, a medium amount of evidence with a medium amount of agreement of evidence) that it will not occur *in the 21st century*. This assessment is weaker than prior assessments, which found that an AMOC collapse in the 21st century was *very unlikely* – evidence published in the years since the Fifth Assessment Report in 2013 added more ambiguity to the assessment of AMOC collapse. Further, evidence is insufficient to support an assessment of the likelihood of collapse beyond the 21st century.

Regarding high-end sea level outcomes driven by rapid ice-sheet mass loss, AR6 (Fox-Kemper et al. 2021) writes:

“Because of our limited understanding of the rate at which some of the governing processes contribute to long-term sea level rise, we cannot currently robustly quantify the likelihood with which they can cause higher sea level rise before 2100 (Stammer et al., 2019).... The [high-end sea level] storyline considers faster-than-projected disintegration of marine ice shelves and the abrupt, widespread onset of marine ice cliff instability (MICI) and marine ice sheet instability (MISI) in Antarctica (Section 9.4.2.4), and faster-than-projected changes in both the surface mass balance and dynamical ice loss in Greenland. While conceptual studies provide medium evidence of these processes, substantial uncertainties and low agreement in quantifying their future evolution arise from limited process understanding, limited availability of evaluation data, missing or crude representation in model simulations, their high sensitivity to uncertain boundary conditions and parameters, and/or uncertain atmosphere and ocean forcing (Sections 9.4.1.2; 9.4.2.2)”

Note that AR6 does not assess these processes as being of low likelihood, but as being not possible to robustly quantify.

Like ice sheet collapse and post-2100 AMOC collapse, many other so-called ‘tipping points’ are of similarly poorly known likelihood, though it is possible to put some constraints on their likelihood at different levels of warming, and in general their likelihood does indeed increase as human activity pushes the Earth system further and further from its historical state (Armstrong McKay et al. 2022). DOE should accordingly clarify that, for many potential abrupt changes, IPCC does not “assign[] low probabilities,” but rather assesses the likelihood to be poorly known, but increasing with global warming.

Notably, an extensive literature addresses decision-making under conditions of deep uncertainty (e.g., Lempert et al. 2024), as in the case of these ‘tipping points’ with poorly known likelihoods. In general, the appropriate response is not to treat such outcomes as of zero expected cost. Such deep uncertainties do pose a challenge to the use of benefit-cost analysis to support decision making (Keller, Helgeson, and Srikrishnan 2021). This literature is not addressed in the report.

Are there alternatives to the social cost of carbon?

This section of our comment is a **technical** comment on section 11.2.5 of the DOE CWG report (p. 125).

This brief report section addresses the question of whether estimates of the SCC are useful for policymakers. The value of uncertain social cost estimates is a long running discussion in economics; as one example, see Baumol (1972). This literature is not referenced.

This section confuses the SCC as a ‘regulatory instrument’ (presumably referring to its use as a metric in regulatory impact analyses) with the SCC as a metric of marginal damages caused by a tonne of carbon dioxide. The latter is clearly an appropriate topic for a report on “impacts of greenhouse gas emissions.” The former is about policy choices, not a description of impacts, and seems beyond scope. Accordingly, section 11.2.5 should be removed. If it is not removed, the broad base of relevant literature needs to be reviewed.

The statement that “Many emissions regulations (such as electric vehicle mandates, renewable energy mandates, energy efficiency regulations and bans on certain types of home appliances) cost far more per tonne of abatement than any mainstream SCC estimate” is an uncited assertion without evidence. Of course, as discussed above, the report’s definition of ‘mainstream’ is idiosyncratic, as it likely refers to the left tail of SCC estimates highlighted in red in Figure 1 and leaves the bulk of SCC estimates, not discussed in the report, to be ‘not mainstream.’ This statement should be removed.

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Response to Chapter 12: Global climate impacts of U.S. emissions policies

R. Katz-Rosene (University of Ottawa); L. Freese (University of California, Irvine); P. Mahdavi (University of California, Santa Barbara); J. West (University of North Carolina)

This final chapter of the DOE CWG report, beginning on **page 129**, and concluding on **page 131**, makes the case that U.S. policy action on climate mitigation will have a minimal effect on the global climate, and that these effects will only take place after a long period of time: “U.S. policy actions are expected to have undetectably small direct impacts on the global climate and any effects will emerge only with long delays.”

The framing of this chapter is built upon several logical fallacies about the US contribution to global climate change, and upon premises which are inconsistent with longstanding established scientific and institutional understandings of the need for collective action, and the responsibilities of all nations in cooperating on climate change mitigation. This chapter also makes multiple false statements about current scientific understanding in order to minimize the impact of CO2 in the immediate future and at the local level.

Global climate change is understood to be a “global commons problem” due to the long lifetimes of the main greenhouse gases and the global response of the climate system. As such, emissions from one location today affect climate in ways that are distributed globally and in time into the future. The DOE CWG report implies that even large actions to reduce US GHG emissions will cause small climate reduction benefits to the US itself. However, that statement would also be true for every other nation considering mitigation. For a commons problem of this nature, collective action where many nations all take action is essential to achieve a better global solution (Ostrom 1990).

Response to 12.1:

Comment: Technical, Editorial

First, the DOE CWG report claims that there is a “scale problem” such that U.S. emissions have minimal global impact, stating that “even drastic local actions will have negligible local effects” (p.129). This is a misrepresentation of both present and historical data on U.S. emissions of greenhouse gases which have had, and continue to have, a substantial effect on the global climate to date, in absolute terms and relative to other nations.

- U.S. annual fossil emissions of CO₂ (territorial) in 2023 (the latest year for which the Global Carbon Project has reliable data) show the United States to have *the second largest emissions of all countries that year* (at 4,911.4 million tonnes of CO₂). This equates to 13% of World emissions of CO₂ that year. This means the U.S. emits more CO₂ annually than all other countries, with the sole exception of China (Global Carbon Project 2024).
- Data from the EDGAR database on total greenhouse gas emissions, which includes CO₂, methane, and other greenhouse gases, similarly shows the outsized footprint of U.S. emissions. In 2023, the U.S. was the *second-largest emitter* with 5,960.8 million tonnes of CO₂e, or 11% of the world total (Crippa et al. 2024).
- Cumulative U.S. fossil emissions of CO₂ (territorial), from 1850 to 2023, show that the U.S. has emitted 431,683 million tonnes of CO₂ during this period. This is *more than any other country's cumulative fossil CO₂ emissions*, and equivalent to 23.9% of World fossil CO₂ emissions over this time (Global Carbon Project 2024)
- According to Ritchie et al. (2023), cumulative U.S. CO₂ emissions from fossil fuels, cement, land use, and land use change and forestry combined, from 1850 to 2023, show the US is the largest emitter of all countries, at 559.32 billion tonnes CO₂. This is equivalent to 21.3% of World cumulative anthropogenic CO₂ emissions during this same period. Therefore the US has likely contributed more than any other country to ambient CO₂ concentrations and warming experienced to date.
- As per the IPCC (2021), anthropogenic CO₂ emissions from 1750 through to 2019 have contributed to an estimated change in Global Mean Surface Temperature of roughly 0.95°C. The vast majority (more than 99.9%) of cumulative anthropogenic CO₂ emissions occurred after 1850 (Ritchie et al. 2023). Based on the additionality of cumulative CO₂ emissions, it is reasonable to conclude that the U.S. is responsible for an equivalent (~21.3%) amount of the warming that has occurred so far (see Evans 2021 for similar estimates).
- Putting historical emissions aside, the DOE CWG report frames U.S. emissions as relatively small in a way that downplays the significance of current and future emissions without regulation. To properly assess the impact of U.S. climate policy, however, one cannot look only at a single year's emissions. What matters is how regulation alters the trajectory of emissions in future years, since the climate impacts of CO₂ depend on *cumulative emissions*.
- The premise of the United Nations Framework Convention on Climate Change (UNFCCC), which the U.S. signed and ratified in 1992 – and to which the US is still a party – acknowledges that climate change is a collective problem requiring action on behalf of *all nations*, as no single country can achieve the goals of the UNFCCC on its

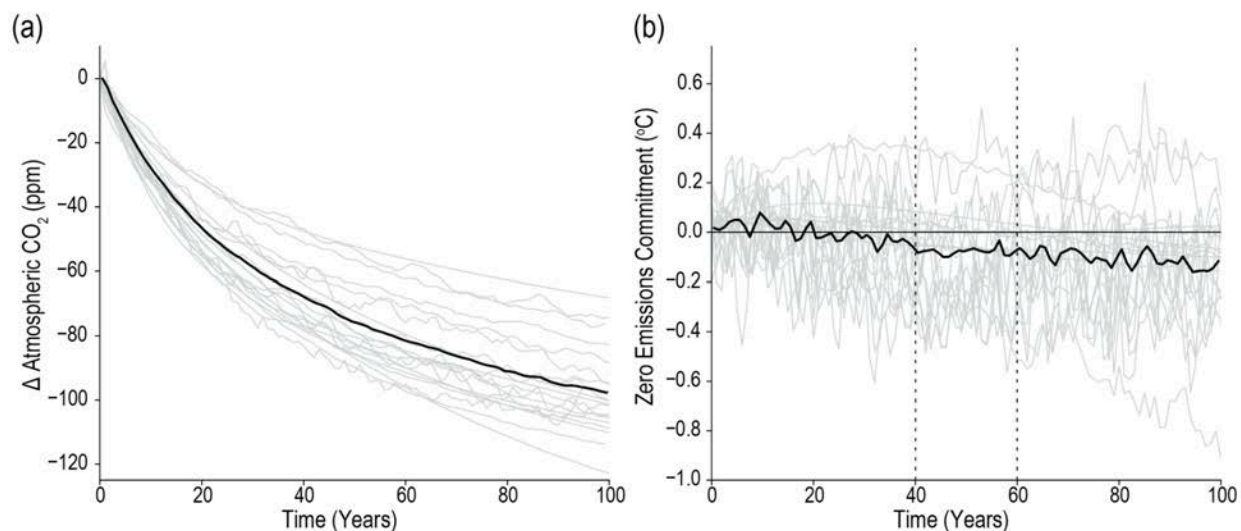
own. It states on the first page, that “the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions” (United Nations 1992, 1).

- Clause 2.a (p.6) of the UNFCCC asserts that “Parties shall adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs”. Further, the Convention asserts that “developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions” (p.6) – including specifically emissions of carbon dioxide (United Nations 1992). It thus stands to reason that under the US’ obligations to the UNFCCC, further action to limit anthropogenic emissions of CO₂ is required.
- As a party to the UNFCCC, the U.S. further agreed that “States have ... the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction” (p. 2).
- Given that the US contribution to radiative forcing from CO₂ to date is objectively “large” given its status as the highest-emitting cumulative country (at nearly one fifth) of cumulative CO₂, it stands to reason that the U.S. bears a proportionally significant responsibility to lead in emissions reductions under the principles of the UNFCCC. This further illustrates the misrepresentative assertion in the DOE CWG of “only a very small global effect” (p. 129).
- To address these issues, the DOE CWG would need to:
 - Revise its characterization of the “small” scale of U.S. emissions, and provide context of U.S. emissions relative to other countries.
 - Reframe U.S. emissions in terms of more than just one individual year, as that is not a scientifically rigorous or politically relevant method of accounting.
 - Discuss the role of the U.S in the broader global community and of climate change as a global commons collective action problem, and the role of common but differentiated responsibilities of nations in collectively mitigating climate change.

Comment: Technical

Second, the DOE CWG falsely states “And even if global emissions were to stop tomorrow, it would take decades or centuries to see a meaningful reduction in the global CO₂ concentration and hence human influences on the climate.”

- Stopping all CO₂ emissions would lead to a meaningful reduction in global CO₂ concentrations, as is shown in the figure below. Surface warming stays level because it is a balance between the radiative forcing due to CO₂ in the atmosphere and energy take-up by the ocean. Stopping global emissions tomorrow would lead to an immediate decline in CO₂ concentration, one that is actually more rapid in the years immediately after cessation. From research in the zero emissions commitment model intercomparison project (ZECMIP) (Jones et al. 2019): “By 50 years after emissions cease in the A1 experiment, the change in atmospheric CO₂ concentration ranged from –91 to –52 ppm, with a mean of –76 ppm and median of –80 ppm,” where A1 is a 1% increase in CO₂ until 1000 PgC of emissions are reached, and then emissions are zeroed (MacDougall et al. 2020).
- This is also discussed in the IPCC AR6 WG1 report, as seen in Figure 4-39 below. In line with the work discussed above, this figure is showing the response to a cessation of CO₂ shows the immediate decline in CO₂ concentrations and that shows that warming stops basically immediately when emissions cease.



From [Fig. 4-39](#) of the IPCC AR6 WG1 report: “**Figure 4. 39 | Zero emissions commitment (ZEC).** Changes in (a) atmospheric CO₂ concentration and (b) evolution of global surface air temperature (GSAT) following cessation of CO₂ emissions branched from the 1% per year experiment after emissions of 1000 Pg C (Jones et al., 2019; MacDougall et al., 2020). ZEC is the temperature anomaly relative to the estimated temperature at the year of cessation. ZEC₅₀ is the 20-year mean GSAT change centred on 50 years after the time of cessation (see Table 4.8) –

this period is marked with the vertical dotted lines. Multi-model mean is shown as a thick black line, individual model simulations are in grey. Further details on data sources and processing are available in the chapter data table (Table 4.SM.1)."

Comment: Technical, Editorial

Third, on pages 129-131, DOE CWG frames U.S. policy action as if it exists within a global policy vacuum, having no relative effect on the actions of other nations or the international community. In contrast, numerous lines of evidence suggest that U.S. policy action has spillover effects on the global community.

- A report by Elkerbout et al. (2024) shows how the U.S. Inflation Reduction Act (IRA) catalyzed European climate policy shifts, noting that “the Net-Zero Industry Act (NZIA) was adopted by the EU’s Council of Ministers on May 27, 2024, and has been referred to as the European Union’s response to the US Inflation Reduction Act.” (p. 4). The authors find that the EU’s climate policy shifted after the release of the IRA, from primarily supporting early-stage innovation to prioritizing the deployment and market penetration of strategic net-zero technologies, a clear strategic pivot which increased policy ambition.
- Similarly, work by Mehling (2024) and Larsen et al. (2023) has contributed to a broader literature pointing to potential spillover effects of US climate policy in other countries.

As Mehling summarizes:

- “Research suggests that the IRA could not only help significantly reduce the distance between forecast emissions levels and the U.S. Nationally Determined Contribution (Bistline et al. 2023; Jenkins et al. 2023) while already evidencing signs of a resurgence in U.S. manufacturing (Bermel et al. 2023), but it is also expected to lower the costs of clean technologies, benefiting other countries through knowledge diffusion and technology transfer, and over time unlocking greater deployment of clean technologies outside the U.S. than within its borders” (Mehling 2024, 24).
- Similarly, Mehling adds, in reference to Larsen et al. (2023), that “one study has estimated that, on a cumulative basis, the incentives included in the IRA for certain emerging climate technologies could reduce 2.4-2.9 tons of emissions outside the U.S. for every ton reduced within the U.S.”
- Broadly, there is an extensive literature on policy diffusion that shows how the adoption of a policy in one jurisdiction spreads by influencing the policy choices of other governments (see Shipan and Volden 2012 for a review). This extends to climate policy

as well, in the contexts of carbon pricing (Linsenmeier et al. 2023) and industrial policy (Meckling and Strecker 2023).

- It thus stands to reason that ambitious climate policies in the United States are likely to generate positive spillover effects – encouraging greater action and ambition abroad. Conversely, a rollback of U.S. climate efforts could produce *negative* spillovers, potentially weakening international resolve and slowing the pace of global decarbonization.
- To address these issues the DOE CWG would need to:
 - Incorporate recent research that clearly shows the influence of U.S. regulation and policy on more than just the U.S., and how that type of spillover has carried through with climate policy and regulation, thus making the clear tie that U.S. choices impact more than the U.S.

Comment: Technical, Reference

Fourth, DOE CWG falsely states that CO₂ has a time-delayed impact: “Any change in local CO₂ emissions today will have only a very small global effect, and only with a long delay” (p.129):

- The claim that there is a “long delay” before effects are felt is incorrect. Immediately after emissions, CO₂ has an impact on radiative forcing in the atmosphere that then lasts for hundreds to thousands of years, due to the long lifetime of CO₂. The authors are making a misleading argument, confusing long lifetimes with long delays in impact. The impact is almost immediate, with warming stopping immediately after emission cessation, and concentrations immediately declining (see Figure 4-39 from the IPCC AR6 WG1 report, above)
- This combination— one in which CO₂ emissions have an *immediate* impact on radiative forcing, while also having a *long* lifetime, actually means that their impact is not only *immediate* but also *long lasting* and can accumulate over long time periods.
- Although closing one individual coal plant, or changing one combustion vehicle to an electric vehicle will have a small impact, U.S. policy has much wider reach, impacting entire sectors that total to 4.7 gigatons of CO₂ emissions *annually* (6 gigatons of CO₂ equivalent) (U.S. Energy Information Administration 2025). Beyond this, U.S. policy impacts other countries and future time periods, leading to a compounding impact on global CO₂ emissions.
- Thus, if we combine the logic of U.S. emissions compounding year on year, with the fact that CO₂ does have an immediate and long lasting impact, this leads to an opposing conclusion to one that the authors draw.

- To address these problems, the DOE CWG would need to:
 - Correct their clearly false statement that CO₂ does not have an immediate impact, as upon being emitted it impacts radiative forcing and thus temperatures.
 - Discuss the long lifetime of CO₂, and thus the importance of cumulative impacts of year on year emissions of CO₂ given its immediate impacts.
 - Remove language on a long delay in CO₂ impacts, given that this is untrue.

Comment: Technical, Editorial

Fifth, DOE CWG implies that US policy actions going forward will have a limited impact: “Any change in local CO₂ emissions today will have only a very small global effect, and only with a long delay” (p.129). This is demonstrably false:

- According to a November 2024 analysis by Climate Action Tracker, current policies and actions in the U.S. put the country on track for a reduction of roughly 29%–39% below 2005 levels by 2030, *excluding land use, land use change, and forestry (LULUCF)*. This represents a shortfall in emissions reductions required to meet the U.S. target under the Nationally Determined Contribution of 50-52% below 2005 levels by 2030 (Climate Action Tracker 2024). The analysis rates this level of action as “insufficient”, meaning that if all countries were to follow a similar scale of emissions change, global warming would likely exceed 2°C and could reach up to 3°C by the end of the century. Meanwhile, if the U.S. were to increase policy ambition and successfully bring emissions down by at least 62%–65% below 2005 levels by 2030 (including emissions from land use, land use change and forestry, or LULUCF), this level of action would be compatible with a 1.5°C warming trajectory (if all other nations pursued the same level of action) (Climate Action Tracker 2024).
- According to the Global Carbon Project 2024, the remaining carbon budget to limit global warming to 2.0°C is 1,110 Gt of CO₂ (Global Carbon Project 2024). A simple comparative exercise for two distinct emissions pathways demonstrates how the DOE CWG report’s claim that “any change in local CO₂ emissions today will have only a very small global effect” (p. 129) is demonstrably false: Consider, for instance, the difference between an emissions trajectory in which U.S. fossil CO₂ emissions remain at present day levels (roughly 4.9 Gt CO₂ per year) for the remainder of the 21st Century (75 years, for illustrative purposes), as compared to a scenario in which U.S. fossil CO₂ emissions decline to ‘Net Zero’ by 2050 (in 25 years). In the former case, cumulative CO₂ emissions by end of Century are 367.5 Gt CO₂, eating up *a third* of the global remaining

CO2 budget, and leaving all of the rest of the international community to the remaining *two thirds* of the budget. In the second Net Zero scenario, U.S. cumulative fossil emissions might feasibly total roughly 64 Gt CO2 by end of the century (or less than 6% of the remaining budget). In this scenario, the U.S.’ more ambitious CO2 reduction leaves much more space for other nations to use a fair share of the remaining budget for 2.0°C. As such, it can be fairly stated that U.S. action has a substantial effect on the international community’s ability to remain within the global carbon budget.

- To address these comments the DOE CWG needs to:
 - Show how different future emissions trajectories impact cumulative emissions outcomes by the end of this century, and how these different emissions scenarios impact the remaining carbon budget for 2.0°C warming of pre-Industrial levels.

Comment: Reference, Technical

Sixth, DOE CWG mischaracterizes and misuses evidence from Lomborg (2016) in quoting that the study “estimated that full compliance with the initial commitments in the Paris Accord would not stop warming, it would only prevent about 0.1C warming and delay hitting the baseline year 2100 temperature levels by about a decade” (p. 129).

- We assume the DOE CWG are discussing the emissions from the entire world, given that the authors claim ‘full compliance... would not stop warming’. However, these are the ‘initial commitments’, as Lomborg (2016) himself states. His ‘optimistic’ scenario holds a reduction of 28% of CO2 emissions by 2025 until 2100, which is not in line with current policies and goals from the United States, as the current Nationally Determined Contribution that reflects updated U.S. policies is to reduce greenhouse gas emissions by 50-52% below 2005 levels by 2030 and 61-66% by 2035 (United States of America 2021). This use of emission reduction estimates that are far below the current commitments contribute to a large underestimate of the impact of the Paris Accord and the United States’ NDCs.
- Beyond this, it is known that the current NDCs are not even enough to meet the ultimate Paris Accord goals. So the United States has a smaller impact that is necessary to meet the goals of the accord. Thus, the DOE CWG report’s line of argument relies on the US failing to meet its commitment in the Paris Accord and only following old policies, rather than the impact of meeting the Paris Accord.

- Based on work that includes both NDCs and INDCs, the expected temperature increase due to current policies is 2.7°C to 3.2°C by 2100 (Rogelj et al. 2016; Hausfather 2025).
- To address this issue, the DOE CWG would need to:
 - Incorporate the most up-to-date literature on the impacts of current U.S. climate policy, as well as scenarios in which U.S. policy aligns with the Paris Accord. Relying instead on outdated policy assumptions that fall well short of Paris objectives results in a clear underestimate of the U.S.’s impact.

Comment: Technical, Editorial

Seventh, the DOE CWG states: “Thus, in contrast with conventional air pollution control, even drastic local actions will have negligible local effects, and only with a long delay. The practice of referring to unilateral U.S. reductions as ‘combatting climate change’ or ‘taking action on climate’ on the assumption we can stop climate change therefore reflects a profound misunderstanding of the scale of the issue.” (p.129).

- As discussed above, the statement of a ‘long delay’ is false.
- Again, as discussed above, this statement assumes that the United States’ actions do not impact other countries, when in fact, they do (Mehling 2024; Larsen et al. 2023).
- The statement of ‘negligible local effects’ is incorrect. The United States’ emissions do impact the global mean temperature, and, thus, local temperature. The Fifth National Climate Assessment (Crimmins et al. 2023, 1–5): “The effects of human-caused climate change are already far-reaching and worsening across every region of the United States. Rapidly reducing greenhouse gas emissions can limit future warming and associated increases in many risks.”
- Conventional air pollution has both *immediate* and *long-term impacts*, and much of the regulation surrounding air pollution is meant to reduce these long-term impacts from continued inhalation of polluted air (Pope 2000; McDuffie et al. 2021).
- Furthermore, air pollution is not just local— a critical issue regarding air quality is the transboundary and trans-continental spread of pollutants, as is addressed through the Convention on Long Range Transport of Pollutants.
- Actions to reduce GHG emissions can bring important reductions in US air pollutants emitted from the same sources, with local and near-term benefits to health that exceed costs in the large majority of studies (West et al. 2023).
- To address these concerns, the DOE CWG would need to:

- Properly define what they mean by a ‘long delay’, given that CO2 emissions have an immediate impact on radiative forcing and thus temperature, and their cessation leads to immediate decreases in temperature and concentrations
- Explain that the majority of people in the U.S., therefore, will feel the immediate impact of CO2 emissions.
- And, thus, describe the local impacts that would occur to people in the U.S., such as changes in temperature, extremes, and more.
- Re-evaluate their statement that conventional air pollution is local, and situate CO2 better within the span of various pollutants and their health impacts.

Response to 12.2:

Comment: Technical, Editorial

Eighth, the DOE CWG argues that because the climate impacts of regulations on just one economic sector are minimal, then the climate impacts of “the most aggressive regulatory actions on GHG emissions” (p. 130) are small.

- Using the case of U.S. motor vehicle emissions, the DOE CWG justifies the limited impacts of emissions regulations in general by limiting their impact analysis to a single sector. This is a deceptive rhetorical tool referred to as the fallacy of inconsequentialism (Sandler 2010). Such statements have been used in the context of climate change to justify continued emissions by any individual given the globality of anthropogenic emissions (Sandberg 2011).
- To address this problem, the DOE CWG needs to:
 - Re-assess the United States contributions to emissions (cumulatively) and thus assess climate change through a lens that is not driven by inconsequentialism but rather by the accumulation of collective action across sectors and activities.

Comment: Technical, Editorial

Ninth, the DOE CWG asserts that the emissions reductions from regulations on U.S. motor vehicles are not large because the 1.05 billion tonnes of CO2 from U.S. cars and light trucks “amount for only 3.0 percent of global energy-related CO2 emissions” (p. 130).

- This is a false equivalence, as the appropriate comparison would be to global vehicular emissions rather than all worldwide energy-related emissions. Estimates from Lekaki et al. (Lekaki et al. 2024) using the EDGAR database show that global road transport emissions in 2020 (the most recent year of reliable available data for global

road-transport emissions) were 6.204 billion tonnes of CO₂. Thus emissions from U.S. cars and light trucks amount to 16.9 percent of global road-transport CO₂ emissions, which is nearly six times larger than the 3.0 percent of total emissions stated in the DOE CWG, and by itself a considerable share of emissions.

- Furthermore, temperature is related to cumulative CO₂ emissions. Thus, comparing one individual year of U.S. motor vehicles is an irrelevant argument to the impact that it has on climate. The U.S. would not stop motor vehicle emissions for one year only from a regulation; this regulation would have a time-compounding impact on emissions over multiple years.
- The DOE CWG claims that reductions in U.S. vehicle emissions would be unmeasurable. However, even if we cannot directly measure the temperature response of a particular policy, that doesn't mean we cannot estimate its impact. Given our high-confidence understanding of the physics of the climate system, fine tuned over the last 200 years, we can make good estimates of the impacts of any CO₂-reduction policy. While there is uncertainty in any calculation like this, the uncertainty is bounded and the bounds do not include zero.
- To address these issues, the DOE CWG would need to:
 - Re-assess the impact of United States emissions in accordance with their cumulative future impacts, particularly due to policies that will have a longer than one year timescale

Response to 12.3:

Tenth, the concluding paragraph of DOE CWG Chapter 12 (p.130) creates a false impression of a static world in which other nations are not themselves seeking to reduce GHG emissions. The conclusion fails to consider the role that US action or inaction influences international ambition, since the US is the second most important emitter currently, and most important historically. It further fails to accurately account for the historical contribution made by US CO₂ emissions to cumulative anthropogenic CO₂ concentration increases, and fails to accurately assess the contribution made by US greenhouse gas emissions to anthropogenic radiative forcing to date. Finally, it fails to accurately model how different future GHG policy trajectories within the U.S. might influence the global climate in the future, and how different global GHG policy outcomes might influence the domestic climate within the US.

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Public Comment on the DOE Climate Report: Climate Change Impacts to Wildlife and Biodiversity

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Comment Type: Technical, Entire DOE report: pp. 1-139.

Summary: The DOE's July 2025 review of climate impacts of greenhouse gas emissions provides no substantive discussion of climate change impacts on U.S. wildlife and biodiversity, mentioning "biodiversity" only once (p. 80) and never mentioning "wildlife". This omission ignores a large and growing body of evidence showing that greenhouse gas-driven climate change is already causing species declines, range shifts, phenological mismatches, mass die-offs, and heightened extinction risks in both terrestrial and marine environments.

These systems provide important ecosystem services to humanity. Changes in wildlife and biodiversity can therefore have important negative impacts on humanity. By omitting any discussion of this topic, the report implicitly assigns zero cost to such changes, a conclusion not backed by the peer-reviewed literature. Biodiversity loss is not only an ecological crisis but a direct threat to people, undermining food security, fisheries, and increasing disease risks.

To be scientifically credible, the DOE must add a dedicated synthesis of observed and projected climate impacts on biodiversity, drawing on the best available peer-reviewed science. This synthesis should quantify current and future risks, explain ecological and cascading economic consequences, and address terrestrial, freshwater, and marine environments alike. DOE should also include an economic analysis of biodiversity loss, highlighting costs to agriculture, fisheries, tourism, cultural heritage, and public health.

Introduction: The DOE's *A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate* (July 2025) gives extremely limited attention to climate impacts on wildlife and biodiversity. The report contains no synthesis of climate-driven threats to either wildlife or biodiversity, with the exception of a discussion of effects of ocean acidification on corals (pp. 3, 7, 8, 124). The term "wildlife" does not appear, and "biodiversity" appears only once in passing

(p. 70), in the context of a broader discussion on vegetation changes, without any substantive treatment of the subject. Given the overwhelming evidence that climate change is already harming plant and animal populations in the United States and globally, this omission represents a major gap in the DOE report.

Peer-reviewed studies consistently show that climate change is altering species' ranges, phenology (including migration and flowering timing), physiology, reproductive success, and population viability (Pecl et al. 2017; IPBES 2019; McElwee et al. 2023). More than 3,500 assessed wild animal species globally are threatened with extinction by climate change, with terrestrial and aquatic invertebrates especially at risk (Ripple et al., 2025). Assessing the state of evidence for the US, the Fifth National Climate Assessment Chapter 8 on Ecosystems, Biodiversity and Ecosystem Services notes widespread risks to species and ecosystems, many of which have high economic and cultural values (McElwee et al., 2023).

DOE Report Omissions: Here we provide some examples of topics that should have been but were not included in the DOE report. Rising frequencies of unusually hot days have been linked to heightened local extinction rates, reduced colonization, lower site occupancy, and declines in bumble bee (*Bombus* spp.) species in North America and Europe (Soroye et al. 2020). These pollinator declines threaten food production and ecosystem stability. Without reduction of greenhouse gas emissions, nearly half of insect species and about a quarter of vertebrate species globally could lose most of their geographic ranges by 2100 (Warren et al., 2018). These losses would have severe consequences for ecological relationships, food webs, and human well-being.

Another clear example of climate impacts on food webs are changes in phenology, including documented evidence in the US of changes in timing of seasonal events such as leaf-out and flowering, egg hatching, and migration, among others (McElwee et al., 2023; Inouye, 2022); these changes can lead to timing mismatches where interacting species (such as plants and pollinators) change at different rates (Kharouba et al., 2018). Phenological changes can cause significant economic losses, including increased susceptibility to spring frosts and tourism impacts (Inouye, 2022).

In the U.S. marine environment, climate-driven extreme events have already caused large-scale population die-offs. Since 2018, over 10 billion snow crabs (*Chionoecetes opilio*) in the Bering Sea off Alaska have disappeared, apparently from starvation linked to a marine heatwave (Szuwalski et al., 2023). Similarly, the 2015–2016 North Pacific marine heatwave led to the deaths of an estimated 4 million common murrelets (*Uria aalge*) (Renner et al., 2024) and a ~71% decline in Pacific cod (*Gadus macrocephalus*) abundance, caused by increased metabolic demand and reduced prey availability (Barbeaux et al. 2020). Impacts on U.S. coral reefs are being threatened by ocean acidification (Section 2.2.2), oxygen depletion, marine heat waves and hurricanes that have caused loss of biodiversity and the habitats themselves (Walton et al., 2018; Jones and Gilliam, 2024). The value of US coral reefs in reducing vulnerability to floods and storm damage is valued at more than \$1.8 billion annually (Reguero et al., 2021).

Greenhouse gas-driven climate change is also a major driver of vulnerability to disease among species, including expanded ranges for disease vectors, longer transmission seasons, and altered populations of disease-carrying organisms (Pfenning-Butterworth et al., 2024). Diseases often thrive where other stressors are present (e.g., temperature variation and extreme events, changes in habitats, etc.) (Carlson et al., 2022). Disease and pest outbreaks driven by climate changes and extremes can cause significant economic losses. For example, harmful algal blooms that produce neurotoxins can cause severe impacts on wildlife, human health,

recreational and commercial fisheries, and regional economies: a massive algal bloom of *Pseudo-nitzschia* along the West Coast in spring 2015 linked to a marine heat wave led to delays and closures of the Dungeness crab, rock crab and other fisheries alongside deaths of hundreds of marine mammals and birds, costing tens of millions of dollars in lost revenue (Moore et al. 2019; Trainer et al. 2020).

Recommendations

The DOE should address how climate change is disrupting wildlife and biodiversity through shifting ranges and migration patterns, mismatches between species and their food sources, reduced reproduction and survival, physiological stress from heat extremes, and population declines or extinctions. These changes, including the loss of sea ice-dependent, alpine, and Arctic species and the spread of invasive species, are altering predator-prey relationships, increasing disease risks, and destabilizing ecosystems that underpin human well-being. The resulting economic impacts include reduced pollination and fisheries yields, damage to aquaculture, declines in ecotourism, costs from invasive species and harmful algal blooms, and cultural losses tied to species extinctions. Because ecosystem services are interconnected, such impacts can cascade, amplifying social and economic risks. It is critical to recognize that disruptions to biodiversity directly imperil people. Human well-being is intertwined with the stability of natural systems: from safe food and clean water to disease regulation, mental health, and cultural identity. By neglecting biodiversity impacts, the DOE report misses one of the clearest pathways by which greenhouse gas emissions endanger human health and prosperity.

Without such treatments, the DOE report fails to capture one of the most consequential and clear dimensions of climate change in the US.

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Historical Trends and Climate Change

John Nielsen-Gammon

Part II of the report is devoted primarily to analyses of historical trends.

Analysis of historical trends is one of the three primary lines of evidence for determining the impacts of anthropogenic emissions on the climate system, the other two being simulations of the climate system and basic physical understanding. While climate models have their shortcomings (I call them very accurate simulations of imaginary planets similar to our own), one can conduct experiments with them to isolate various causal factors and their impacts on phenomena large enough to be simulated. Physical understanding is sometimes the most powerful tool, but it is limited by the complexity of the climate system.

The challenge with interpretation of historical trends is that they are affected by many things, such as local changes in land cover, agricultural and forestry practices, instrumentation, ocean temperature patterns, and the randomness of the weather. The focus on historical trends is framed on page 46 as whether there are “statistically significant long-term trends over the available historical record” and on page 93 as “whether a signal has been detected in historical observations”.

Why would the presence of a statistically significant trend be important? It could be a sign of a process in the climate system in need of explanation (rather than just some random variation). More often, though, in the context of scientific knowledge of the climate system, a statistically significant trend can serve as evidence or quantification of a signal predicted by other lines of evidence.

The many factors affecting historical trends means that it's rarely so simple. It's often necessary to account for the effects of all important factors before the magnitude of the climate change factor can be isolated. Alternatively, one can look for key temporal or spatial patterns, or fingerprints, that would only be expected if climate change were the causal mechanism.

What if there's not a statistically significant trend? A moment's thought should be enough to show that the lack of a statistically significant trend, by itself, has very little information content one way or the other. Indeed, to say anything useful about the effect of climate change, it's necessary to account for the other factors and their effects too. If those effects are small enough, it may be possible to put useful upper and lower bounds on the effect of climate change.

If one is interested in the climate change signal, one should focus on as large a geographical area and as long a time series as possible, because the effects of ocean temperature patterns, the randomness of the weather, and local changes in land cover, agricultural and forestry practices become averaged out to varying extents, improving the climate change signal to noise ratio. Once the climate change signal has been detected at the large scale, the question becomes not whether a signal is detectable at every single location (it won't be, because of weather randomness etc.), but how large the local signal ought to be, given the existence of the large-scale signal. Parts of the report do focus on global annual metrics, for which the magnitude of other confounding factors is expected to be small. But others do not.

For example, Figure 6.3.3 showed that record warm season maximum temperatures peaked in the United States in the 1930s. This is clearly not a climate change signal, as no known climate forcings or global climate signals maximized in the 1930s. So how large is the climate change signal? It's very difficult to say. If you're willing to assert that whatever was happening in the early part of the 20th century is no longer happening, then you maybe could look at the trend since 1975 or so and find an upward trend in record highs and an upward (negative) trend in record lows. But really, you need to figure out why extreme temperatures were so large in the 1930s (and 1950s) and subtract out that effect before you could say what the climate change trend is.

The report doesn't do that. That's fine if the objective is simply to report on the historical trend. But the report is titled "A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate", and simply reporting the historical trend and its significance (or lack thereof) in isolation says nothing about the impacts of greenhouse gas emissions.

Given that the trend in extreme heat is dominated (at least prior to 1970) by effects other than climate change, estimates of the magnitude of the effects of climate change must come via other means. Those include climate model simulations, which can be post-calibrated to the historical mean temperature trend, and basic physical understanding of how extreme temperatures ought to be affected by changes in average temperatures.

Figure 5.9 of the DOE CWG report examines a trend that's not the opposite sign of climate models but still substantially different: summertime maximum temperatures in the Corn Belt. This is again a single season, but now also a much smaller area than the whole United States. Thus, natural variability is expected to play a greater role. Since the Corn Belt has been selected for this report precisely because it has the most anomalous regional trend, the a priori expectation would be that natural variability has had a negative effect on maximum temperature trends. Eischeid et al. (2023 JCLim

<https://doi.org/10.1175/JCLI-D-22-0716.1>) confirms this, finding from large ensembles that half or more of the discrepancy between a lower-sensitivity model and observations in recent years is due to unforced precipitation variability. Another potential contributing factor is agricultural intensification in the region, as noted by Eischeid et al. As with the record warm season maximum temperatures, climate models can be and are useful for estimating the trend magnitude that's attributable to climate change as separate from natural variability and agricultural intensification; the difference between models and observations tells us something about the other processes that affect temperature locally and does not automatically mean that there's something wrong with the models.

Section 6.4 examines extreme precipitation trends in three subregions of the United States, collectively representing perhaps 35% of its land area. The choice of small areas (and, in the case of the southeast US, a sparse sampling network) lead to a correspondingly large contribution to natural variability. Nevertheless, there is a notable trend in the number of extreme rainfall events in both the southeast US and the northeast US. In the southeast, the trend in number of events per decade is +0.50, 95% confidence interval -0.18 to +1.17. (All analyses here use ordinary linear regression.) Notice that, because of natural variability, a trend corresponding to a 20% increase in the frequency of extreme rainfall over the past century is nonetheless not statistically significant. In the northeast, the trend in number of events per decade is +1.70, 95% confidence interval +0.66 to +2.74, thus is statistically significant.

To see if there's an overall trend, I combined the counts in the three areas, dividing the northeast counts by two because they represent a smaller geographic area. Perhaps the weight should be even smaller, but the larger number of Pacific Coast stations arguably unduly weights that area higher than the southeast. (Arguably the regression should be negative binomial rather than linear, and with respect to global mean surface temperatures rather than time.) Be that as it may, the aggregate trend is +1.85 events per decade, 95% confidence interval +0.03 to +3.66. This trend, which is marginally statistically significant, corresponds to about a 30% increase in the frequency of extreme rainfall over the past century.

In summary, the smaller the sample size (number of stations, geographical area, time of year, period of record), the more that natural variability and local effects will tend to overwhelm the climate trend. The trend analyses discussed above failed to find a trend (or agreement with climate models) in part because they focused on relatively small areas. The lack of statistical significance does not imply the absence of an underlying climate trend, and more powerful analyses covering broader areas or including more data are needed to determine whether the results from the smaller areas are representative.

In all of the cases discussed above, the report should make clear that the analyses cover limited areas and periods for which the effect of natural variability and local processes are expected to be relatively high, and that more robust analyses for estimating the effect of climate change would cover larger areas and periods.

Comments on the scientific information quality of the DOE CWG report

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These comments address issues related to the DOE CWG report's development process and are in the "other" category. They apply to the entire DOE CWG report.

Summary: The DOE CWG report meets the criteria set by EPA as a Highly Influential Scientific Assessment (HISA) and is subject to EPA criteria because of its preeminent role in an EPA rulemaking. The DOE CWG report fails to meet EPA's standards for information quality required for HISAs used in major agency decisions or actions. The report was not subjected to independent and transparent peer review. The report was not made available for public comment. The report demonstrates a lack of objectivity in its development and its content. Neither DOE nor EPA have provided any compelling reason for failing to follow information quality practices set forth by OMB, DOE, or EPA.

The DOE CWG report meets EPA's criteria as a Highly Influential Scientific Assessment

The DOE CWG report meets EPA's criteria that a Highly Influential Scientific Assessment (HISA): "(i) could have a potential impact of more than \$500 million in any year, or (ii) is novel, controversial, or precedent-setting or has significant interagency interest" (USEPA, 2015) The proposed rule meets both these criteria.

The DOE CWG report is subject to EPA's information quality guidelines

EPA's information quality guidelines apply when it "distributes information prepared or submitted by an outside party in a manner that reasonably suggests that EPA endorses or agrees with it" (USEPA 2002). The preamble to the proposed rule states that "the Administrator received and evaluated" a draft of the DOE CWG report prior to the report's release (USEPA 2025). The DOE CWG report was frequently and prominently cited, demonstrating that EPA does in fact endorse or agree with the report. The DOE CWG report is therefore subject to EPA's information quality guidelines.

The DOE CWG report fails to meet EPA's information quality standards for HISAs

A core component of EPA's Quality System, which is designed to ensure EPA achieves its information quality standards, is rigorous peer review. EPA's Peer Review Handbook states that products deemed to be HISAs "are expected to undergo rigorous external

peer review with opportunities for public participation.” The Handbook further states that, “For ISI and HISAs intended to support the most important decisions, or for work products that have special importance in their own right, the recommended approach is an internal review followed by an external peer review” (USEPA 2015).

A critical characteristic of external peer reviewers is independence, that is, reviewers “are generally not employed by the agency or office producing the document” (OMB 2005). The CWG Report was reviewed only by DOE employees. Further, the review of the CWG Report failed to follow good peer review practices as described by the Office of Management and Budget’s guidelines to ensure transparency, including publication of reviewers’ names, charge questions to the reviewers, reviewers’ comments, and DOE’s response to review comments (OMB2005). Contrary to the EPA peer review guidelines, the review did not provide opportunities for public participation.

The DOE CWG Report demonstrates a lack of objectivity

Per OMB, objectivity “includes whether disseminated information is being presented in an accurate, clear, complete, and unbiased manner” The CWG Report not only fails to demonstrate processes to maximize objectivity, its development and content makes plain its intent to present a biased and predetermined view of climate science. As one climate scientist explained, “Their goal is not to weigh the evidence fairly but to build the strongest possible case for [carbon dioxide’s] innocence. This is a fundamental departure from the norms of science.” (Dessler, Science)

Rather than demonstrating a sincere effort to produce a scientifically objective report, the development process followed by the DOE CWG report instead creates a strong impression of bias toward a specific desired policy outcome. The slate of authors appears to have been selected specifically because of their long-standing critiques of the scientific consensus regarding climate change. The number of authors is small, which greatly reduces the opportunity to hear and incorporate a diverse range of perspectives. DOE did not subject the draft report to independent peer review before presenting the report as suitable for use in a major policy action, with the knowledge that the policy action was contrary to the scientific consensus. The report largely ignores the vast body of climate science except to critique it. Each of these characteristics undermines the perception of objectivity.

Objectivity is impossible to prove, and likely impossible to achieve. Perhaps the report is objective and chooses to only emphasize topics that need to be evaluated further. There is value in such an approach, but it must be conducted in such a manner that builds, rather than undermines, trust. An objective approach would review the full body of evidence on a particular topic, even when emphasizing the need for further evaluation.

When combined with the serious shortcomings of the scientific content, however, the lack of robust processes designed to build confidence in the report's objectivity creates a perception of bias.

Finally, a lack of objectivity does not imply malintent by the authors. Bias can arise well apart from bad faith actions. The processes and procedures described in the OMB and EPA guidelines are designed to substantially increase the objectivity of a research document as well as the perception of objectivity. But it is unrealistic to think that anyone involved in the development of the DOE CWG report could be unaware that the release of the report would stir substantial controversy. For that reason alone, the authors and the Secretary should have insisted on an open and rigorous review process to demonstrate the strength and scientific validity of their conclusions. That they apparently did not insist on such a review makes it more difficult to discount an intention to present conclusions that lack the objectivity essential to a document playing such a crucial role in setting such a consequential policy.

No compelling reason has been provided to waive provisions for peer review

EPA's Peer Review Handbook states that the "Administrator may waive or defer the peer review provisions of the OMB Peer Review Bulletin for ISI [influential scientific information] (including HISAs) if there is a compelling rationale for the waiver or deferral" (EPA 2015). The Handbook also notes that "The use of waivers is expected to be limited to unusual and compelling situations not otherwise covered by the exemptions, such as situations in which unavoidable legal deadlines prevent full implementation of the OMB Peer Review Bulletin's peer review provisions (EPA 2015). However, there is no indication that such waiver or deferral has been granted and there are no "unavoidable legal deadlines" or similar situations that would meet the criteria of "unusual and compelling situations."

Resolution

Given the major issues with the development of the DOE CWG report that have called into question the quality of the scientific information disseminated in the report, DOE has two options to resolve the issues: (1) retract the report; or (2) use the review announced by the National Academies of Sciences, Engineering, and Medicine as a peer review, revise the draft report in response to that review and the relevant comments received from the public, and publish the list of comments and authors' responses on a point-by-point basis.

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DOE CWG Draft Report Citations Review

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A review of the in-text citations and references list in the DOE CWG Draft Report reveals pervasive problems with misrepresentative, inaccurate, and missing citations, citations of non-peer-reviewed pre-prints and blog posts to justify scientific claims, and a high proportion of self-citations by the DOE CWG Draft Report authors.

Misrepresentative, inaccurate, and missing citations: The DOE CWG Draft Report contains 367 in-text citations (non-inclusive of citations of the IPCC and NCA reports) referring to a total of 284 unique references. Of those 367 in-text citations and the references to which they index, at least 22.1% (81 in-text citations or their indexed references) are inaccurate or misrepresentative. An additional 6 in-text citations are entirely missing full references.

Examples of misrepresentation of content from in-text citations include:

- Chapter 1, page 2 of the DOE CWG Draft Report misreports key numbers from a source. The DOE CWG claims that “Allen et al. (2015) reported evidence of diminished performance on some cognitive tasks among workers in office cubicles when exposed to CO₂ levels above 1,000-1,500 ppm.” This in-text citation and associated summary of scientific findings refers to the listed reference for “Allen, J., Macnaughton, P., Satish, U., et al. (2015). Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: A controlled exposure study of green and conventional office environments. *Environmental Health Perspectives*. 124. <https://doi.org/10.1289/ehp.1510037>.” In fact, Allen et al. (2015) studied experimental conditions with targets of 550ppm, 945ppm, and 1400ppm, not a range of “1,000-1,500 ppm,” as the DOE CWG Draft Report claims. While this error may not change the fundamental meaning of the claims related to human exposure to CO₂, it does illustrate how inaccuracies appear not just in the DOE CWG Draft Report citations and reference lists themselves, but also in the descriptions of the studies these citations and references point to.
- Chapter 2, page 3 of the DOE CWG Draft Report contains a similar misrepresentation. The claim that “Haverd et al. (2020) reported a CO₂ fertilization rate much larger than model predictions. That is, CO₂ fertilization had driven an increase in observed global photosynthesis by 30 percent since 1900, versus 17 percent predicted by plant models” overstates the certainty of Haverd et al.’s findings, which predicted 17+/-4%, not 17%.
- Chapter 8, page 88 of the DOE CWG Draft Report cites sources that do not support the claim they are appended to, either because they do not provide the data the DOE CWG states they or or because their data differ significantly what the claim made by the DOE CWG. This section of the DOE CWG includes the claim that, “When the Great Pacific

Climate Shift is accounted for in climate attribution analyses since 1950, 40 percent or more of the warming in the second half of the 20th century is attributed to natural internal variability (McLean et al., 2009; Tung and Zhou, 2013; Chylek et al., 2016; Scafetta, 2021).” The authors of the response to Chapter 8 point out that three of the four sources in this in-text citation do not support the claim in the sentence they are appended to: “Specifically, McLean et al. (2009) and Scafetta (2021) provide no quantitative estimates of the contribution of internal variability to the warming trend. Moreover, the estimate presented in Chylek et al. (2016) is substantially lower than that of Tung and Zhou (2013). According to Chylek et al. (2016), the contribution of the Atlantic Multidecadal Oscillation (AMO) to the 1970–2005 warming was between 0.13 and 0.20 °C (depending on the AMO index used), compared with a greenhouse gas contribution of 0.49–0.58 °C.” [Response to Section 8.3.1]

- In another example of misreporting key details about a source, Chapter 9, page 107 of the DOE CWG Draft Report includes the statement that, “McKittrick (2025) re-examined the Moore et al. database and found that, while it claimed to cover 1,722 studies, only half the entries (N=862) had complete records, so that the sample available for regression analysis was much smaller than both studies indicated.” The authors of the response to Chapter 9 correct this statement: “Nowhere in Moore et al. (2017) is it claimed that 1,722 observations were used for the analysis. Moore et al. (2017) report using 1,010 observations, derived from the subset of Challinor et al. (2014) data relevant to the 4 crops studied (rice, wheat, maize and soybeans), where complete data was either present or could be inferred from reported information.” [Response to Section 9.3]
- Chapter 9, p. 108 of the DOE CWG Draft Report cites a source which cannot “prove” the claim it is appended to. The DOE CWG claims that “Micronutrient deficiency is already a problem in the developing world and dietary supplements have proven to be an effective low-cost response (Ebi et al. 2021).” The authors of the response to Chapter 9 straightforwardly note that this reference cannot support this claim: “Ebi et al. (2021) discuss dietary supplements but do not conclude they have “proven to be an effective low-cost response” to declining nutrient density in crops.” To correct this misrepresentation of the content of Ebi et al. (2021), the DOE CWG Draft Report authors must “remove the statement that dietary supplements have proven to be an effective low-cost response to micronutrient deficiency, or they need to find a source other than Ebi et al. (2021) to support this statement. Ebi et al. (2021) does not make this claim.” [Response to Section 9.4]
- Chapter 11, p. 119 of the DOE CWG Draft Report incorrectly states the object of a reference’s study. While the DOE CWG claims that, “Greßer et al. (2021) developed a regional economic data set for 1,542 sub-national regions around the world between 2005 and 2015 and found temperature had no effect on growth,” in fact, “Gresser, Meierrieks, and Stadelmann (2021) do not study the impact of climate on growth. They study its impact on *output*.” [Response to Section 11.1]

Many more examples of misrepresentation of content are included in comments on specific chapters of the DOE CWG Draft Report.

Examples of inaccurate in-text citations and references include references with sufficient inaccuracies as to appear potentially fabricated as well as relatively more minor errors, such as mismatches between dates on in-text citations and entries in the reference lists, incomplete and incorrect author lists, incorrect DOIs (direct object identifiers), and incorrect pages. Specific examples are:

- Chapter 4, page 28 of the DOE CWG Draft Report cites Lee et al. (2024), indexing to the following reference in that chapter's references list: Lee, S., Byrne, M. P., Loikith, P. C., & O'Dell, C. W. (2024). Zonal contrasts of the tropical Pacific climate predicted by a global constraint. *Climate Dynamics*, 62(1–2), 229–246, <https://doi.org/10.1007/s00382-023-06741-7>. This article, however, does not exist, and the hyperlinked DOI directs to an unrelated 2023 article in the journal *Climate Dynamics* titled “Quantifying the processes of accelerated wintertime Tibetan Plateau warming: outside forcing versus local feedbacks” authored by Mengchu Zhao, Xiu-Qun Yang, and Lingfeng Tao. There is a 2024 article titled “Zonal contrasts of the Tropical Pacific Climate Predicted by a Global Constraint,” but it was authored by Sukyoung Lee, Peter R. Bannon, Mingyu Park, and Joseph P. Clark and published in Volume 61, pp. 669-678 of the *Asia-Pacific Journal of Atmospheric Sciences*, with the assigned DOI of <https://doi.org/10.1007/s13143-024-00373-5>. While the DOE CWG Draft Report authors may have been intending to cite this latter article, it is unclear how the author list, journal title and volume, page numbers, and DOI were incorrectly listed in the report's Chapter 4 reference list.
- Chapter 8, page 90 of the DOE CWG Draft Report includes an in-text citation of “Goesslin et al. (2025),” which indexes to the reference “Goessling, Helge F. Thomas Rackow and Thomas Jung (2024) Recent global temperature surge intensified by record-low planetary albedo. *Science* Vol 387, Issue 6729 pp. 68-73 <https://www.science.org/doi/abs/10.1126/science.adq7280>.” *Science's* publication information (available at <https://www.science.org/doi/abs/10.1126/science.adq7280>) lists 2025 as the correct date.
- Chapter 9, page 105 of the DOE CWG Draft Report includes an in-text citation of “Allen Jr., 2011,” which indexes to the reference “Allen Jr, L. K. (2011). Elevated CO2 increases water use efficiency by sustaining photosynthesis of water-limited maize and sorghum. *Journal of Plant physiology*, 168(16), 1909-1918.” This article has three additional authors (Vijaya Gopal Kakani, Joseph C. V. Vu, and Kenneth J. Boote), who were included in neither the DOE CWG Draft Report's in-text citation or reference list.
- Chapter 2, page 6 of the DOE CWG Draft Report includes an in-text citation of “Zhang et al. (2024),” which indexes to the reference “Zhang, Y., Liu, Y., Chen, X., et al. (2024). Less than 4% of dryland areas are projected to desertify despite increased aridity under climate change. *Nature Communications Earth and Environment*, 5. <https://www.nature.com/articles/s43247-024-01463-y>.” All authors in this reference are incorrect; the correct author list is Xinyue Zhang, Jason P. Evans, and Arden L. Burrell.
- The DOE CWG Draft Report reference list for Chapter 4 (pp. 29-30) includes the reference “Lewis, N. (2023). Objectively combining climate sensitivity evidence. *Climate Dynamics*, 61(9–10), 3155–3163. <https://doi.org/10.1007/s00382-022-06398-8>.” This DOI directs to an entirely different article: Chen, Z., Gan, B., Huang, F. *et al.* The

influence of Pacific-North American teleconnection on the North Pacific SST anomalies in Wintertime under the global warming. *Clim Dyn* **60**, 1481–1494 (2023).
<https://doi.org/10.1007/s00382-022-06398-8>.

- Chapter 2, page 8 of the DOE CWG Draft Report includes an in-text citation of Browman (2016) indexes to “Browman, H. I. (2016). Applying organized scepticism to ocean acidification research. *ICES Journal of Marine Science*, 73(3), 529.1–536.
<https://doi.org/10.1093/icesjms/fsw010>.” The correct page range is 529-536.

The following six in-text mentions of literature do not have references listed in their respective chapter reference lists (six have in-text citations and no reference; one has neither in-text citation nor reference):

1. Chapter 4, p. 28: “About 15 estimates based on historical data appeared in the peer-reviewed literature between 2012 and 2024 yielding ECS best estimates between 1.0°C and 2.5°C, although critics have questioned some of the methods and the data quality.” No in-text citations or references are given to source the claim about 15 estimates based on historical data appearing in the peer-review literature.
2. Chapter 4, p. 25: “The 1979 Charney Report for the U.S. National Academy of Sciences (National Research Council 1979) proposed that the most likely ECS was $3.0 \pm 1.5^\circ\text{C}$.” National Research Council 1979 has no reference listed in the Ch. 4 reference list.
3. Chapter 6, p. 56: “The rise in T_{min} has been strongly related to the growing presence of manufactured surfaces around the weather stations over the last 100+ years (the so-called urban heat island effect; Section 3.3, Karl et al. 1988, Runnals and Oke 2006, and Spencer et al. 2025).” Spencer et al. 2025 has no listed reference in the Ch. 6 reference list.
4. Chapter 6, p. 57: “For example, the 5-day average tropospheric grid-point temperature anomaly over the Pacific NW during that event was +10.8 C, the most extreme Northern Hemisphere grid point summer anomaly in the 46 years from over 4 million grid values. In contrast, the global temperature anomaly during that time was virtually zero (+0.03 C, Mass et al. 2024).” Mass et al. 2024 has no listed reference in the Ch. 6 reference list.
5. Chapter 8, p. 87: “Bronniman et al. (2024) focused on the causes of the cooling in the first decade of the 20th century in the Southern Hemisphere. They found that the cooling was related to a La-Niña-like pattern in the Pacific, a cold tropical and subtropical South Atlantic, a cold extratropical South Pacific, and cool southern midlatitude land areas. The Southern Annular Mode was positive, with a strengthened Amundsen–Bellingshausen seas low, although the spread of the data products is considerable.” Bronniman et al. (2024) has no listed reference in the Ch. 8 reference list.
6. Chapter 9, p. 104: “Deschênes and Greenstone (2007) looked at agricultural profits instead of land values and reached conclusions similar to Mendelsohn et al. (1994), namely that past climatic variations had relatively little effect on farm profitability and that warming would likely yield small overall benefits for the U.S. agricultural sector.” The Ch. 9 reference list includes a reference for the 2012 reply by Deschênes and Greenstone to critiques, but not a reference for the original 2007 paper.

Citations of non-peer-reviewed pre-prints and blog posts to justify scientific claims: Of the DOE CWG Draft Report's 284 unique references, 4 are to Substack posts ("Pielke Jr., R. (2025, May 8). RIP NOAA's billion dollar disasters. The Honest Broker [Substack]. <https://rogerpielkejr.substack.com/p/rip-noaas-billion-dollar-disasters>"; "Pielke Jr., Roger (2024) Weather Attribution Alchemy. Substack essay <https://rogerpielkejr.substack.com/p/weather-attribution-alchemy>") and non-peer-reviewed pre-prints ("Pielke Jr., Roger and Ritchie, Justin (2020) "Systemic Misuse of Scenarios in Climate Research and Assessment" Social Sciences Research Network April 2020, available at: <https://ssrn.com/abstract=3581777>"; "McKittrick, Ross R (2025) Consistent Climate Fingerprinting. Climate Dynamics forthcoming preprint available at www.rossmckittrick.com"). These are cited 7 times in the DOE CWG Draft Report to justify scientific claims.

Self-citations by the DOE CWG Draft Report authors: Self-citations (citations to work on which they are a sole or co-author) by the DOE CWG Draft Report authors make up a notably high proportion of both in-text citations and unique references. 10.9% (40) of the report's in-text citations are self-citations; these index to 8.8% (25) of the report's 284 unique references. In chapters 3 and 5, more than a quarter of in-text citations are self-citations (Table 1).

Chapter	In-Text Citations	Self-Citations	% Self-Citations
1	3	0	0.00%
2	32	0	0.00%
3	37	10	27.03%
4	22	2	9.09%
5	17	5	29.41%
6	52	6	11.54%
7	9	0	0.00%
8	80	9	11.25%
9	26	1	3.85%
10	29	0	0.00%
11	56	7	12.50%
12	4	0	0.00%
<i>Total</i>	367	40	10.90%

Table 1. Total count of in-text citations, total count of self-citations, and percentage of self-citations by chapter.

Median rates of self-citation vary across disciplines, so this rate cannot be interpreted as universally high. However, this rate is notably high in relation to the self-citation rates by authors in IPCC reports. For the IPCC Working Group 1 contribution to AR6, for example, self-referencing rates for each chapter and their respective authors ranged from 1.2% to 5.1% with a mean of 2.4% (Chavelli & Connors, 2023). This relative proportion suggests an

inappropriate overreliance on their own work by the DOE CWG Draft Report authors and a concomitant lack of inclusion of report by the many other experts on the topics covered in the report.

References

Chavelli, F., & Connors, S. (2023). Analysis of the WGI contribution to the Sixth Assessment Report: Review of the WGI AR6 references. Zenodo. <https://doi.org/10.5281/zenodo.7615825>

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Katja Matthes is Director of the GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany and Professor of Atmospheric Physics. She earned her Ph.D. in Meteorology from the Free University of Berlin in 2003. Her research focuses on climate variability, solar influences on

climate, and ocean-atmosphere interactions. Matthes is a co-author of the IPCC Sixth Assessment Report and has led multiple international climate modeling initiatives. She is a board member of the German Alliance for Marine Research and a key contributor to the UN Ocean Decade and European as well as international marine and climate policy efforts.

Pamela McElwee is a Professor in the Department of Human Ecology at Rutgers University. She earned her Ph.D. in Forestry & Environmental Studies and Anthropology from Yale University in 2003. Her interdisciplinary research focuses on biodiversity conservation, ecosystem services, and climate change mitigation and adaptation in land systems, with extensive fieldwork in Southeast Asia and the U.S.. McElwee served as a Lead Author for the IPCC Special Report on Climate Change and Land (2019), the IPBES Global Assessment (2019), the Fifth U.S. National Climate Assessment (2023), the cancelled Sixth U.S. National Climate Assessment, as co-chair of the IPBES Nexus Assessment (2024), and will be a lead author on the WG3 report of AR7 for IPCC.

Karen McKinnon is an Associate Professor at UCLA in the Department of Atmospheric and Oceanic Sciences, the Department of Statistics and Data Science, and the Institute of the Environment and Sustainability and. She earned her Ph.D. in Earth and Planetary Sciences from Harvard University in 2015. Her research focuses on large-scale climate variability, internal temperature and precipitation variability, and the predictability of extreme events. McKinnon develops statistical and computational methods to analyze climate data and improve projections. She is a 2021 Packard Fellow in Science and Engineering, a 2023 Kavli Fellow, and she has co-authored 45 peer reviewed publications in climate science and statistics.

Carl Mears* is a Senior Scientist at Remote Sensing Systems, where he has worked since 1998. He earned his Ph.D. in Physics from the University of California, Berkeley in 1991. Mears is known for developing satellite temperature records using MSU and AMSU data and has contributed to climate data reconciliation efforts. He was a contributing author to the IPCC Fourth Assessment Report and a convening lead author for the U.S. Climate Change Science Program's first synthesis report.

C. Andrew Miller retired from EPA's Office of Research and Development, where he served as Associate Director for Climate in the Air, Climate, and Energy research program. He earned his Ph.D. in mechanical engineering from North Carolina State University in 1991. He was EPA's representative to the U.S. Global Change Research Program, overseeing development and publication of three National Climate Assessments. Miller received the 2018 Dixy Lee Ray award from the American Society of Mechanical Engineers for his work to advance environmental engineering and policy.

Noah Molotch is a Professor of Geography at the University of Colorado Boulder and a Fellow of the Institute of Arctic and Alpine Research. He earned his Ph.D. in Hydrology and Water Resources from the University of Arizona in 2004. He is former General Chair of the Western Snow Conference and former Director of the Center for Water, Earth Science, and Technology

(CWEST). His research focuses on snow hydrology, ecohydrology, and remote sensing in mountainous regions, with implications for water resource management.

Frances C. Moore is a Professor in the Department of Environmental Science and Policy at UC Davis, where she also serves as Hurlston Presidential Chair in the Department of Environmental Science and Policy and as a UC Davis Chancellor's Fellow. She earned her Ph.D. in Environment and Resources and M.A. in Economics from Stanford University in 2015, and an M.E.Sc. from Yale in 2010. Her research integrates climate science and economics to study climate impacts on human welfare, adaptation, and policy. Moore served as a Senior Economist in the Council of Economic Advisers focusing on climate and environmental policy from 2022-2023.

Philip Mote is a Professor in the College of Earth, Ocean, and Atmospheric Sciences at Oregon State University and former Dean of the Graduate School. He earned his Ph.D. in Atmospheric Sciences from the University of Washington and a B.A. in Physics from Harvard University. Mote directed the Oregon Climate Change Research Institute 2009-19 and research includes regional climate modeling and impacts, scenario development, and climate communication. He was a lead author of the cryosphere chapter in two IPCC reports, contributed to four National Climate Assessments including two as Northwest chapter lead, and has served on ten committees of the National Academies of Science, Engineering, and Medicine.

Rebecca B. Neumann is an Associate Professor in Civil and Environmental Engineering at the University of Washington. She earned her Ph.D. from MIT and holds B.S. and B.A. degrees from Rice University. Her research in hydro-biogeochemistry explores subsurface flow, biogeochemical reactions, and carbon cycling, with applications to climate change and environmental health. Neumann was a NOAA Climate and Global Change Postdoctoral Fellow and received a Department of Energy Early Career Research Award and AGU Falkenberg Award.

Chan-Pang Ng is a climate scientist affiliated with the University of Washington and Peking University. He earned his Ph.D. in Meteorology from Peking University. His research focuses on extreme precipitation, hailstorms, and synoptic-scale weather systems, particularly in China.

John Nielsen-Gammon is a Professor of Atmospheric Sciences at Texas A&M University and the Texas State Climatologist. He earned his Ph.D. in Meteorology from MIT. He served as President of the American Association of State Climatologists from 2022 to 2024. His research involves drought, precipitation, air pollution meteorology, and climate change. He is a Fellow of the American Association for the Advancement of Science and the American Meteorological Society..

David S. Nolan is Professor of the Department of Atmospheric Sciences at the University of Miami's Rosenstiel School of Marine, Atmospheric, and Earth Science. He earned his Ph.D. in Earth and Planetary Sciences from Harvard University in 1996 and a B.A. in Physics from Harvard College in 1990. Nolan's research focuses on the dynamics of hurricanes, tornadoes,

and tropical meteorology, including the development of the Weather Research and Forecasting (WRF) model for tropical cyclone forecasting and research. He served on the drafting committee for the American Meteorological Society's Statement on Climate Change and has contributed to NOAA's Hurricane Forecasting Improvement Program.

Stephen Po-Chedley is an atmospheric scientist whose research focuses on satellite-based climate observations, climate sensitivity, and model evaluation. He earned his Ph.D. in Atmospheric Sciences from the University of Washington in 2016.

Ben Poulter is a Senior Scientist at Spark Climate Solutions and formerly led greenhouse gas feedback research at NASA Goddard Space Flight Center. He earned his Ph.D. in Earth and Environmental Sciences from Duke University in 2005. His expertise includes carbon cycle modeling, methane budgets, and land-atmosphere interactions. Poulter served as Deputy Director of the White House Office on Greenhouse Gas Measurements and contributed to the IPCC Fifth and Sixth Assessment Reports, the Fifth National Climate Assessment, and the Global Methane Budget.

James Rae is a Reader in the School of Earth and Environmental Sciences at the University of St Andrews. He earned his undergraduate degree from the University of Oxford and his Ph.D. in Earth Sciences from the University of Bristol. Rae's research reconstructs past climate change using geochemical proxies in sediments, fossils, and ice cores, with a focus on CO₂ dynamics and ocean acidification. He held a NOAA Climate and Global Change Fellowship at Caltech and a major ERC-funded grant on long-term pH and CO₂ change. He is a member of the Young Academy of Scotland and is Director of the St Andrews Centre for Changing Climates.

Kimberley Reid is a Research Fellow at the University of Melbourne in the School of Geography, Earth, and Atmospheric Sciences. She earned her Ph.D. from the University of Melbourne in 2022, where she also completed her B.Sc. and M.Sc. She worked as a Postdoctoral Researcher at Monash University until 2024. Her research focuses on atmospheric rivers, extreme rainfall, and tropical-extratropical interactions over Australia and New Zealand. Reid has published 14 peer-reviewed studies on extreme rainfall, climate variability and synoptic weather. She has also provided evidence to Australian government inquiries on recent high impact extreme rainfall events, and received the 2024 AMOS Science Outreach award.

William J. Ripple is a University Distinguished Professor and Richardson Endowed Chair at Oregon State University. He is Director of the 27,000 member Alliance of World Scientists. He earned his Ph.D. from Oregon State University. He led the article- "World Scientists' Warning of a Climate Emergency" with more than 15,000 scientist signatories. Since 2023, he has been co-lead author of the annual series "The State of the Climate Report" published by BioScience. His work spans climate policy, biodiversity, climate feedbacks, climate vital signs, ecological overshoot, and sustainable food systems. He has authored more than 200 scientific journal articles.

Shaina Sadai is a climate scientist and critical physical geographer whose research integrates climate modeling, sea level rise, and climate justice. She earned her Ph.D. in Geosciences from UMass Amherst in 2022 and holds an M.S. in Applied Mathematics and dual B.S. degrees in Astronomy/Astrophysics and Physics. Sadai was the Hitz Fellow at the Union of Concerned Scientists, where she supported climate litigation and assessed emissions from major polluters. Her work informs legal cases at international courts and contributes to climate justice scholarship.

Scott Saleska* is a Professor of Ecology and Evolutionary Biology at the University of Arizona. His research focuses on biogeochemical ecology, carbon cycling, and ecosystem-climate interactions, particularly in tropical forests and thawing permafrost. Saleska uses remote sensing, micrometeorology, and bioinformatics to study ecological feedbacks to climate. He earned his Ph.D. in Energy and Resources from UC Berkeley in 1998. He is a fellow of the Ecological Society of America.

Enrique Sánchez is a Professor of earth physics at the Environmental Sciences, biochemistry and physics faculty at the Universidad de Castilla-La Mancha (UCLM). He earned his Ph.D. in Physics (Geophysics and Meteorology) at Universidad Complutense de Madrid in 2002. His research focuses on regional climate modeling, mostly studying climate extremes and regional climatic processes. He has been part of the main international european intercomparison regional climate modelling exercises in the past 20 years, including 7 EU projects, and currently involved in CORDEX community. Sánchez coordinated the CLIVAR-Spain Committee (2012-2020), and has around 70 peer-reviewed studies and 150 contributions to international conferences, related specially on Mediterranean climate dynamics.

Benjamin M. Sanderson is a Research Director of the climate mitigation group at CICERO (Center for International Climate Research) in Oslo, Norway. He holds a Ph.D. in Atmospheric, Oceanic and Planetary Physics from the University of Oxford and has previously worked at the National Center for Atmospheric Research in Boulder, CO and CERFACS in Toulouse, France. His research focuses on climate model uncertainty, emission scenarios, and risk-based approaches to climate mitigation. Sanderson has contributed both to US National Climate Assessments and to IPCC assessments, particularly in scenario development and uncertainty quantification, and is a lead author of the Scenarios and projected future global temperatures chapter in the upcoming 7th IPCC assessment report.

Benjamin D. Santer is an Honorary Professor in the School of Environmental Sciences at the University of East Anglia in England. He earned his Ph.D. in Climatology from the University of East Anglia's Climatic Research Unit in 1987. Santer is renowned for his work in climate detection and attribution, using statistical methods to identify human fingerprints in climate records. He was the Convening Lead Author of Chapter 8 in the IPCC Second Assessment Report (1995), which concluded that "the balance of evidence suggests a discernible human influence on global climate." He is a member of the U.S. National Academy of Sciences and the recipient of a MacArthur Fellowship and the Carl-Gustaf Rossby Research Medal.

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Richard Seager* is the Ewing Lamont Research Professor at the Lamont-Doherty Earth Observatory of Columbia University. He earned his Ph.D. in climate dynamics from Columbia University. His research covers climate variability and change on timescales of weeks to millennia, with a focus on atmosphere-ocean interactions, hydroclimate dynamics, and droughts. He is a fellow of AGU and AMS.

Adam Sobel is a Professor of Applied Physics and Applied Mathematics and of Earth and Environmental Sciences at Columbia University. He earned his Ph.D. in Meteorology from MIT in 1998. His research focuses on extreme weather events, tropical meteorology, and climate risk assessment. He is also a science communicator, author of the book *Storm Surge* (about Hurricane Sandy) as well as many op-eds and mainstream media articles, and host of the podcast *Deep Convection*. He is a Fellow of the American Geophysical Union and the American Meteorological Society.

Vivek Srikrishnan is an Assistant Professor in the Department of Biological & Environmental Engineering at Cornell University. He earned his Ph.D. in Energy & Mineral Engineering from Penn State University in 2018. He researches climate risk management strategies, focusing on quantifying climate and socioeconomic uncertainties and their implications for resilience. Srikrishnan's work spans flood risk, energy systems, and adaptation planning

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Abigail L.S. Swann is a Professor of Atmospheric and Climate Science and Professor of Biology at the University of Washington. She earned her Ph.D. in Earth and Planetary Science from the University of California, Berkeley. Her research examines biosphere-climate feedbacks, particularly how vegetation influences climate through evapotranspiration and carbon cycling. Swann serves as co-chair of the Community Earth System Model's biogeochemistry working group.

Cyrus Taylor is the Albert A. Michelson Professor of Physics at Case Western Reserve University. He earned his Ph.D. in Physics from the Massachusetts Institute of Technology. Originally focused on high-energy particle physics, Taylor pivoted toward climate change

research after witnessing glacial retreat on Mount Kilimanjaro. He now teaches and researches climate modeling and climate change physics, including model validation and carbon dioxide dynamics. He is a Guggenheim Fellow and a Fellow of the American Physical Society.

Richard S.J. Tol is a Professor of Economics at the University of Sussex and Vrije Universiteit Amsterdam, specializing in environmental and climate economics. He earned his M.Sc. in Econometrics and Operations Research (1992) and Ph.D. in Economics (1997) from Vrije Universiteit Amsterdam. Tol has contributed to the IPCC Fifth Assessment Report as a Coordinating Lead Author for Working Group II. His research focuses on the economic impacts of climate change and cost-benefit analyses of climate policy. He is a member of the Academia Europaea and a Fellow of the Royal Economic Society and listed among the top 100 economists in the world

Louis Verchot is an Emeritus Scientist, formerly the Leader of the Land Restoration Group at the Alliance of Bioversity International and CIAT and leader of the CGIAR Initiative on low Emissions Food Systems. He earned his Ph.D. in forestry from NC State University and has worked extensively on land use, agriculture, and climate mitigation. Verchot has contributed to the IPCC since 2003, including as a Lead Author on the 2019 Special Report on Climate Change and Land. His work focuses on greenhouse gas inventories, land restoration, and climate-smart agriculture, with field experience across Africa, Latin America, and Southeast Asia.

John M. Wallace is Professor Emeritus of Atmospheric Sciences at the University of Washington. He earned his Ph.D. from MIT in 1966. Wallace is a leading expert on climate variability. He co-authored the textbook *Atmospheric Science: An Introductory Survey*, a leading textbook in the field. He is a co-recipient of the 2024 Japan Prize for foundational work contributing to the prediction of extreme weather events. He is a member of the National Academy of Sciences and has served on numerous National Research Council panels advising the government on matters related to climate ability and change.

Katja Weigel is a Research Scientist at the University of Bremen and affiliated with the Earth System Model Evaluation and Analysis Department at the German Aerospace Center (DLR). She earned her Ph.D. in Physics of the Atmosphere from the University of Wuppertal in 2009. She specializes in machine learning for Earth system modelling and analysis, model evaluation, and extreme event detection. Her work contributes to the Collaborative Research Centre 181 "Energy Transfers in Atmosphere and Ocean" as one of the leaders in the subproject "Climate Model Intercomparison". She was a contributing author for Chapter 3 of the IPCC Sixth Assessment Report.

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Emily L. Williams is a Postdoctoral Scientist at the Sierra Nevada Research Institute and Climatology Lab at UC Merced. She earned her Ph.D. in Geography from UC Santa Barbara in 2022, where she was an NSF GRFP fellow and recipient of the Lancaster Dissertation Award. Her research combines climate attribution science and social science, with a primary focus on drought-related impacts in the western US. Williams has published on how climate change has exacerbated drought conditions in the western US, as well as on organizational climate denial.

Christopher C. Witt is a Professor of Biology at the University of New Mexico and Director of the Museum of Southwestern Biology. He earned his Ph.D. in Biological Sciences from Louisiana State University in 2004. His research includes avian systematics, molecular evolution, and high-altitude adaptation, with a focus on Neotropical birds and climate impacts on montane species.

Lucas Vargas Zeppetello is an Assistant Professor in the Department of Environmental Science, Policy, and Management at UC Berkeley. He earned his Ph.D. in Atmospheric Science from the University of Washington in 2021. His research focuses on land-atmosphere interactions, heat waves, soil moisture dynamics, and ecohydrology. He was a James S. McDonnell Foundation Fellow at Harvard and received the AGU Holton Award. His work informs climate variability and terrestrial carbon cycle modeling.

EXHIBIT C

Order No. 202-25-3

Pursuant to the authority vested in the Secretary of Energy by section 202(c) of the Federal Power Act (FPA), 16 U.S.C. § 824a(c), and section 301(b) of the Department of Energy Organization Act, 42 U.S.C. § 7151(b), and for the reasons set forth below, I hereby determine that an emergency exists in portions of the Midwest region of the United States due to a shortage of electric energy, a shortage of facilities for the generation of electric energy, and other causes, and that issuance of this Order will meet the emergency and serve the public interest.

Emergency Situation

The Midcontinent Independent System Operator (MISO) faces potential tight reserve margins during the summer 2025 period, particularly during periods of high demand or low generation resource output. The North American Electric Reliability Corporation (NERC) released its 2025 Summer Reliability Assessment on May 14, 2025. In its assessment, NERC indicated that “[d]emand forecasts and resource data indicate that MISO is at elevated risk of operating reserve shortfalls during periods of high demand or low resource output.”¹ In particular, the retirement of thermal generation capacity creates the potential for electricity supply shortfalls. NERC anticipates that the near-term period of highest capacity shortfall for MISO will occur in August.²

Multiple generation facilities in Michigan have retired in recent years. According to the U.S. Energy Information Administration (EIA), “[s]ince 2020, about 2,700 megawatts of coal-fired generating capacity have been retired and no new coal-fired facilities are planned.”³ Additionally EIA stated, “[t]ypically Michigan’s nuclear power plants have supplied about 30% of in-state electricity, but the amount of electricity generated by nuclear power plants in Michigan has declined as plants have been decommissioned.”⁴ The state’s Big Rock Point nuclear power plant shut down in 1997 and the Palisades nuclear power plant closed in 2022. While the Palisades nuclear power plant may reopen in 2025, it will not be available during the peak demand period this summer.

The 1,560 MW J.H. Campbell coal-fired power plant in West Olive, MI, is scheduled to cease operations on May 31, 2025. Its retirement would further decrease available dispatchable generation within MISO’s service territory, removing additional such generation along with the other 1,575 MW of natural gas and coal-fired generation that has retired since the summer of 2024. In 2021, Consumers announced that it planned to “speed closure” of Campbell in 2025, several years before the end of its scheduled design life.⁵ Although MISO and Consumers have

¹ 2025 summer reliability assessment. (May 14, 2025).

https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SRA_2025.pdf

² *Id.*

³ U.S. Energy Information Administration, Michigan State Energy Profile, Oct. 17, 2024, *available at*: <https://www.eia.gov/state/print.php?sid=mi>.

⁴ *Id.*

⁵ <https://www.consumersenergy.com/news-releases/news-release-details/2021/06/23/consumers-energy-announces-plan-to-end-coal-use-by-2025-lead-michigans-clean-energy-transformation>

incorporated the planned retirement into their supply forecasts and acquired a 1,200 MW natural gas power plant in Covert, MI, the NERC Assessment still anticipates “elevated risk of operating reserve shortfalls.”

MISO’s Planning Resource Auction Results for Planning Year 2025-26, released in April 2025, note that for the northern and central zones, which includes Michigan, “new capacity additions were insufficient to offset the negative impacts of decreased accreditation, suspensions/retirements and external resources.” While the results “demonstrated sufficient capacity,” the summer months reflected the “highest risk and a tighter supply-demand balance” and the results “reinforce the need to increase capacity.”⁶

ORDER

Given the determination that an emergency exists as discussed above, the responsibility of MISO to ensure reliability of its system, and the ability of MISO to identify and dispatch generation necessary to meet load requirements, I have determined that, under the conditions specified below, additional dispatch of the Campbell Plant is necessary to best meet the emergency and serve the public interest for purposes of FPA section 202(c). This determination is based on the insufficiency of dispatchable capacity and anticipated demand during the summer months, and the potential loss of power to homes and local businesses in the areas that may be affected by curtailments or outages, presenting a risk to public health and safety.

This Order is limited in duration to align with the emergency circumstances. Because the additional generation may result in a conflict with environmental standards and requirements, I am authorizing only the necessary additional generation on the conditions contained in this Order, with reporting requirements as described below.

FPA section 202(c) requires the Secretary of Energy to ensure that any 202(c) order that may result in a conflict with a requirement of any environmental law be limited to the “hours necessary to meet the emergency and serve the public interest, and, to the maximum extent practicable,” be consistent with any applicable environmental law and minimize any adverse environmental impacts.

Based on my determination of an emergency set forth above, I hereby order:

- A. From the time this Order is issued on May 23, 2025, MISO and Consumers Energy shall take all measures necessary to ensure that the Campbell Plant is available to operate. For the duration of this order, MISO is directed to take every step to employ economic dispatch of the Campbell Plant to minimize cost to ratepayers. Following conclusion of this Order, sufficient time for orderly ramp down is permitted, consistent with industry practices. Consumers Energy is directed to comply with all orders from MISO related to the availability and dispatch of the Campbell Plant.

⁶ <https://cdn.misoenergy.org/2025%20PRA%20Results%20Posting%2020250428694160.pdf>

- B. To minimize adverse environmental impacts, this Order limits operation of dispatched units through the expiration of the Order. MISO shall provide a daily notification to the Department (via AskCR@hq.doe.gov) reporting whether the Campbell Plant has operated in compliance with the allowances contained in this Order.
- C. All operation of the Campbell Plant must comply with applicable environmental requirements, including but not limited to monitoring, reporting, and recordkeeping requirements, to the maximum extent feasible while operating consistent with the emergency conditions. This Order does not provide relief from any obligation to pay fees or purchase offsets or allowances for emissions that occur during the emergency condition or to use other geographic or temporal flexibilities available to generators.
- D. By June 15, 2025, MISO is directed to provide the Department of Energy (via AskCR@hq.doe.gov) with information concerning the measures it has taken and is planning to take to ensure the operational availability and economic dispatch of the Campbell Plant consistent with the public interest. MISO shall also provide such additional information regarding the environmental impacts of this Order and its compliance with the conditions of this Order, in each case as requested by the Department of Energy from time to time.
- E. The extent to which MISO's current Tariff provisions are inapposite to effectuate the dispatch and operation of the units for the reasons specified herein, the relevant governmental authorities are directed to take such action and make accommodations as may be necessary to do so.
- F. Consumers is directed to file with the Federal Energy Regulatory Commission Tariff revisions or waivers necessary to effectuate this order. Rate recovery is available pursuant to 16 U.S.C. § 824a(c).
- G. This Order shall not preclude the need for the Campbell Plant to comply with applicable state, local, or Federal law or regulations following the expiration of this Order.
- H. This Order shall be effective upon its issuance, and shall expire at 00:00 EDT on August 21, 2025, with the exception of the reporting requirements in paragraph D and applicable compliance obligations in paragraph E.
- I. Issued in Washington, D.C. at 3:15:pm Eastern Daylight Time on this 23rd day of May 2025.



Chris Wright
Secretary of Energy

cc: **FERC Commissioners**

Chairman Mark Christie
Commissioner David Rosner
Commissioner Lindsay S. See
Commissioner Judy W. Chang

Michigan Public Service Commissioners

Chairman Dan Cripps
Commissioner Katherine Peretick
Commissioner Alessandra Carreon

EXHIBIT D

Order No. 202-25-7

Pursuant to the authority vested in the Secretary of Energy by section 202(c) of the Federal Power Act (FPA), 16 U.S.C. § 824a(c), and section 301(b) of the Department of Energy Organization Act, 42 U.S.C. § 7151(b), and for the reasons set forth below, I hereby determine that an emergency exists in portions of the Midwest region of the United States due to a shortage of electric energy, a shortage of facilities for the generation of electricity, and other causes. Issuance of this Order will meet the emergency and serve the public interest.

Order No. 202-25-3

J.H. Campbell Generating Plant (Campbell Plant) is a 1,420 MW coal-fired plant primarily owned by Consumers Energy Company (Consumers) and located in West Olive, MI. In 2021, Consumers announced that it planned to implement a “speed closure” of the Campbell Plant fifteen years before the end of its scheduled design life.¹ Instead of retiring the Campbell Plant at the end of its design life, Consumers planned to accelerate the Campbell Plant’s retirement and discontinue its operations on May 31, 2025.

Order No. 202-25-3, issued pursuant to FPA section 202(c), required that the Campbell Plant remain in operation for 90 days, until August 21, 2025. That order was based on my determination that emergency conditions existed in the region served by the Midcontinent Independent System Operator, Inc. (MISO). Specifically, I determined that MISO likely faced tight reserve margins during the summer 2025 period, particularly during periods of high demand or low generation resource output. I determined that the continued operation of the Campbell Plant would provide additional generation capacity during these periods which would help prevent the potential loss of power to homes and local businesses in the areas that might have been affected by curtailments or outages that would otherwise pose a risk to public health and safety. I determined that the continued operation of the Campbell Plant was necessary to alleviate immediate and anticipated threats to reliability. My determination was based on a number of facts.

First, the North American Electric Reliability Corporation (NERC) released its 2025 Summer Reliability Assessment on May 14, 2025. In its assessment, NERC indicated that “[d]emand forecasts and resource data indicate that MISO is at elevated risk of operating reserve shortfalls during periods of high demand or low resource output.”² In particular, NERC explained that the retirement of thermal generation capacity increased the likelihood of electricity supply

¹ See *Consumers Energy Announces Plan to End Coal Use by 2025; Lead Michigan’s Clean Energy Transformation*, Consumers Energy (June 23, 2021), <https://www.consumersenergy.com/news-releases/news-release-details/2021/06/23/consumers-energy-announces-plan-to-end-coal-use-by-2025-lead-michigans-clean-energy-transformation>. As a coal-fired facility, it would be difficult for the Campbell Plant to resume operations once it has been retired. Specifically, any stop and start of operation creates heating and cooling cycles that could cause an immediate failure that could take 30-60 days to repair if a unit comes offline.

² *2025 Summer Reliability Assessment*, North American Electric Reliability Corporation, at 16 (May 2025), https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SRA_2025.pdf (NERC 2025 Summer Reliability Assessment).

shortfalls. NERC anticipated that the near-term period of greatest capacity shortfall for MISO would likely occur in August.³

Second, multiple generation facilities in Michigan have retired in recent years. According to the U.S. Energy Information Administration (EIA), “[s]ince 2020, about 2,700 megawatts of coal-fired generating capacity have been retired and no new coal-fired facilities are planned.”⁴ Additionally, EIA stated, “[t]ypically, Michigan’s nuclear power plants have supplied about 30% of in-state electricity, but the amount of electricity generated by nuclear power plants in Michigan has declined as plants have been decommissioned.”⁵ The state’s Big Rock Point nuclear power plant shut down in 1997, and the Palisades nuclear power plant closed in 2022. While the Palisades nuclear power plant may reopen in 2025, it was not projected to be available during the peak demand period this summer.⁶

Third, the Campbell Plant’s retirement would have further decreased available dispatchable generation within MISO’s service territory, adding to the loss of the other 1,575 MW of natural gas and coal-fired generation that has retired since the summer of 2024. Although MISO and Consumers have incorporated the planned retirement of the Campbell Plant into their supply forecasts and Consumers acquired a 1,200 MW natural gas power plant in Covert, MI, the NERC Assessment still anticipates “elevated risk of operating reserve shortfalls.”⁷

Fourth, MISO’s Planning Resource Auction Results for the 2025-2026 Planning Year, released in April 2025, noted that for the northern and central zones, which includes Michigan, “new capacity additions were insufficient to offset the negative impacts of decreased accreditation, suspensions/retirements and external resources.”⁸ While the results “demonstrated sufficient capacity,” the summer months reflected the “highest risk and a tighter supply-demand balance” and these results “reinforce the need to increase capacity.”⁹

Continuing Emergency Conditions

The emergency conditions that led to the issuance of Order No. 202-25-3 continue, both in the near and long term. The summer season has not yet ended, and the production of electricity from the Campbell Plant will continue to be a critical asset to maintain reliability in MISO this summer. That need is evidenced by the fact that the Campbell Plant was called on by MISO to generate large amounts of electricity during the heat wave that hit MISO this past June. According

³ *Id.*

⁴ *Michigan State Profile and Energy Estimates*, U.S. Energy Info. Admin. (Oct. 17, 2024), <https://www.eia.gov/state/print.php?sid=MI>.

⁵ *Id.*

⁶ The start-up of Palisades is scheduled for the fourth quarter of 2025.

⁷ NERC 2025 Summer Reliability Assessment at 16.

⁸ *Planning Resource Auction—Results for Planning Year 2025–2026*, Midcontinent Independent System Operator, Inc., 13 (May 29, 2025), https://cdn.misoenergy.org/2025%20PRA%20Results%20Posting%2020250529_Corrections694160.pdf (MISO Planning Resource Auction – Results for Planning Year 2025-26).

⁹ *Id.* at 2,12.

to the U.S. Environmental Protection Agency’s data, over the month of June, the Campbell Plant generated approximately 664,000 MWh, running at 61% capacity.¹⁰ In fact, between June 11 and August 18, MISO issued dozens of alerts to manage grid reliability in its Central Region in response to hot weather, severe weather, high customer load, forced generation outages, and transfer capability limits. MISO issued alerts for the Central Region on at least 40 of the 69 days between June 11 and August 18. In June, MISO issued alerts affecting the Central Region on 18 days, including an Energy Emergency Alert (EEA) level 1 ("Max Gen Step 1b") on June 23 to enable MISO to take emergency action to ensure grid stability, including bringing additional resources online.¹¹ The Central Region had alerts on 21 days in July, including one Max Generation Warning on July 29 and two Max Generation Alerts on July 28 and 29.¹² Two Capacity Advisory Initiate alerts have been issued in August to date.¹³ Moreover, the May 2025 NERC Summer Reliability Assessment referenced a Seasonal Outlook issued by the National Oceanic and Atmospheric Administration (NOAA), which estimates that much of the Midwest has a 33%-40% chance to experience above-normal temperatures this summer.¹⁴ The Seasonal Outlook released by NOAA on July 17, 2025, increased this estimate for much of the region to a 40%-50% chance.¹⁵

MISO’s resource adequacy problems are not limited to the summer. In 2022, MISO requested Federal Energy Regulatory Commission (FERC) approval of its filing to revise its resource adequacy construct (including the Planning Resource Auction or PRA) to establish capacity requirements for each of the four seasons of the year rather than on an annual basis determined by peak summer demand.¹⁶ MISO justified this revision by explaining that “Reliability risks associated with resource adequacy have shifted from ‘Summer only’ to a year-round

¹⁰ See, *Custom Data Download*, EPA CAMPD (Clean Air Markets Program Data), <https://campd.epa.gov/data/custom-data-download> (search criteria to produce these results could include Emissions >> Monthly >> Unit (default) >> Apply >> “2025” and “June.” The data can then be filtered to only include the Campbell Plant.)

¹¹ An Energy Emergency Alert is an alert declared by the Transmission Provider in accordance with the NERC Operating Manual associated with the Transmission Provider’s inability to provide for the Energy and Operating Reserve requirements of the MISO Balancing Authority Area. For more information, see MISO, FERC Electric Tariff, Module A, § 1.E (Definitions) (92.0.0). For more information on Energy Emergency Alert levels, see North American Electric Reliability Corporation. (n.d.). *EOP-011-1 Emergency Operations*. <https://www.nerc.com/pa/stand/reliability%20standards/eop-011-1.pdf>.

¹² A Max Gen Alert occurs when MISO is forecasting a potential capacity shortage. A Max Gen Warning is a warning to prepare for a possible Max Gen Event. See MISO Operating Procedures, <https://efis.psc.mo.gov/Document/Display/9379> (20180920).

¹³ A Capacity Advisory alert is an advisory issued based on the potential for limited operating capacity margins (<5%) in the following 2-3 days. See MISO Operating Procedures, <https://efis.psc.mo.gov/Document/Display/9379> (20180920).

¹⁴ NERC 2025 Summer Assessment at 9.

¹⁵ *Seasonal Outlook*, NOAA Climate Prediction Ctr., (July 17, 2025), https://www.cpc.ncep.noaa.gov/products/predictions/long_range/seasonal.php?lead=1.

¹⁶ *Midcontinent Independent System Operator, Inc.*, FERC Docket No. ER22-495-000 (Nov. 30, 2021). This request was approved by FERC on August 31, 2022. *Midcontinent Independent System Operator, Inc.*, 180 FERC ¶ 61,141 (2022).

concern.”¹⁷ MISO noted that over 60 percent of all “MaxGen” events (events when MISO initiates emergency procedures because of concerns over the adequacy of available generation) occurred outside of the summer season.¹⁸

In December of 2023, MISO released an “Attributes Roadmap,” in which it presented “an in-depth look at the challenges of operating a reliable bulk electric system in a rapidly transforming energy landscape.”¹⁹ Among other things, this report described changes in the time of year during which the risk of the loss of load was greatest. For the 2023/24 Planning Year, the greatest risk of loss of load was in the summer, but it is expected that by the summer of 2027, there will be an equal loss of load risk in both the summer and fall seasons. MISO also projects that the risk of loss of load in the winter and spring seasons, although not as high as in the summer or fall, will nevertheless increase over time.²⁰

More recently, MISO affirmed the resource adequacy problems occurring outside of its summer season in its 2024 report entitled, “*MISO’s Response to the Reliability Imperative*.”²¹ In a section of that report entitled “Risks in Non-Summer Seasons,” MISO again stressed that it has resource reliability concerns outside of the summer season.

Widespread retirements of dispatchable resources, lower reserve margins, more frequent and severe weather events and increased reliance on weather-dependent renewables and emergency-only resources have altered the region’s highest historic risk profile, creating risks in non-summer months that rarely posed challenges in the past.²²

These MISO studies indicate that the emergency conditions caused by the loss of generation capacity in MISO extend past the summer season.

The evidence indicates that there is also a potential longer term resource adequacy emergency in MISO. When MISO reported the results of its PRA for the 2025-26 Planning Year, it noted that “new capacity additions were insufficient to offset the negative impacts of decreased accreditation, suspensions/retirements and external resources” in the northern and central zones, which include Michigan.²³

On June 6, 2025, subsequent to the issuance of Order No. 202-25-3, the Organization of MISO States (OMS) and MISO issued the results of their survey, which has been conducted annually for many years to determine the degree to which expected capacity resources satisfy

¹⁷ MISO Transmittal Letter at 3, FERC Docket No. ER22-495-000 (Nov. 30, 2021).

¹⁸ *Id.* at 3-4.

¹⁹ *Attributes Roadmap*, MISO (Dec. 2023), <https://cdn.misoenergy.org/2023%20Attributes%20Roadmap631174.pdf>.

²⁰ *Id.* at 11.

²¹ *MISO’s Response to the Reliability Imperative*, MISO (Updated Feb. 2024), <https://cdn.misoenergy.org/2024+Reliability+Imperative+report+Feb.+21+Final504018.pdf>.

²² *Id.* at 12.

²³ MISO Planning Resource Auction – Results for Planning Year 2025-26 at 13.

planning reserve margin requirements.²⁴ The 2025 Survey presented projections of resource adequacy for the summer of 2026 and subsequent years. Although the survey projected a potential capacity surplus for the summer of 2026, it also projected that at least 3.1 GW of additional generation capacity beyond currently committed generation capacity must be added to meet the projected planning reserve margin.²⁵ The survey also projected that there would be insufficient capacity to meet the peak demand for electricity in each of the following four summers, increasing from a deficit of 1.4 GW in 2027 to 8.2 GW in 2030.²⁶ Similar results were projected for MISO's winter seasons, with a small surplus of generation capacity in 2026, followed by increasing deficits the following four years.²⁷

The primary reasons for these projected deficits also are shown on the OMS-MISO survey. Large amounts of existing generation capacity are projected to be retired each year while, at the same time, the demand for electricity is projected to increase at an accelerating pace.²⁸ Although the OMS-MISO survey projects generation capacity to continue to increase in the coming years with the addition of new potential generation assets, the increase in capacity is largely offset by the projected retirements, and does not keep up with the growth in demand.²⁹

MISO has been taking steps to address these projected deficits. For example, on June 6, 2025, MISO submitted a proposal to FERC to establish an Expedited Resource Addition Study (ERAS) process to provide a framework for the expedited study of interconnection requests to address urgent resource adequacy and reliability needs in the near term. This proposal was approved by FERC on July 21, 2025.³⁰ The ERAS process should help expedite the construction of needed new capacity. However, resources studied under the ERAS will have commercial operation dates that are at least three years away, and are provided an additional three year grace period to commence commercial operations.³¹ In addition, supply chain constraints impeding the acquisition of critical grid components, including large natural gas turbines and transformers, are likely to further hinder rapid construction and exacerbate reliability concerns.³² Consequently, the new ERAS process is unlikely to result in the addition of any new generation capacity in the next few years.

²⁴ 2025 OMS-MISO Survey Results, OMS and MISO (Updated June 6, 2025) <https://cdn.misoenergy.org/20250606%20OMS%20MISO%20Survey%20Results%20Workshop%20Presentation702311.pdf>.

²⁵ *Id.* at 2.

²⁶ *Id.* at 7.

²⁷ *Id.* at 9.

²⁸ *Id.* at 7, 9.

²⁹ *Id.*

³⁰ *Midcontinent Independent System Operator, Inc.*, 192 FERC ¶ 61,064 (2025).

³¹ 192 FERC ¶ 61,064 at P 84.

³² See generally, *US Gas-Fired Turbine Wait Times as Much as Seven Years; Costs Up Sharply*, S&P Global (May 2025), [US gas-fired turbine wait times as much as seven years; costs up sharply | S&P Global](#). “With demand for natural gas-fired turbines in the US rapidly accelerating amid power demand growth forecasts driven by AI, manufacturing, and electrification, wait times for turbines are anywhere between one and seven years depending on the model, and costs have increased considerably, experts told Platts.”

Order 202-25-3 was preceded by executive orders on January 20, 2025, and April 8, 2025, in which President Donald J. Trump underscored the dire energy challenges facing the Nation due to growing resource adequacy concerns. Specifically, in Executive Order 14262, “Strengthening the Reliability and Security of the United States Electric Grid,” President Trump emphasized that “the United States is experiencing an unprecedented surge in electricity demand driven by rapid technological advancements, including the expansion of artificial intelligence data centers and increase in domestic manufacturing.”³³ President Trump likewise recognized, in Executive Order 14156, “Declaring a National Energy Emergency,” that the “United States’ insufficient energy production, transportation, refining, and generation constitutes an unusual and extraordinary threat to our Nation’s economy, national security, and foreign policy.”³⁴ The Executive Order adds: “Hostile state and non-state foreign actors have targeted our domestic energy infrastructure, weaponized our reliance on foreign energy, and abused their ability to cause dramatic swings within international commodity markets.”³⁵

The Department’s July 2025 Resource Adequacy Report: Evaluating the Reliability and Security of the United States Electric Grid, issued pursuant to the President’s directive in Executive Order 14262, details the myriad challenges affecting the Nation’s energy outlook. “Absent decisive intervention, the Nation’s power grid will be unable to meet projected demand for manufacturing, re-industrialization, and data centers driving artificial intelligence (AI) innovation.”³⁶ The prolific growth of data centers for the development of AI, as well as their immense energy needs, presents a new and unexpected source of load growth. This growth is illustrated by the fact that there are more than twenty AI companies operating in Michigan alone.³⁷ In addition, as just one example, Consumers has announced an additional 1 GW of new power to a planned hyperscale data center and “continue[s] to see positive momentum with data centers within the 9 GW pipeline”³⁸

Grid operators—including MISO itself—have likewise acknowledged the Nation’s current energy crisis. For instance, during a March 25, 2025, hearing before the House Committee on Energy and Commerce, Jennifer Curran, Senior Vice President, Planning and Operations, MISO, testified that “the MISO region faces resource adequacy and reliability challenges due to the

³³ Executive Order No. 14262, 90 Fed. Reg. 15521 (Apr. 8, 2025) (*Strengthening the Reliability and Security of the United States Electric Grid*), <https://www.whitehouse.gov/presidential-actions/2025/04/strengthening-the-reliability-and-security-of-the-united-states-electric-grid/>.

³⁴ Executive Order No. 14156, 90 Fed. Reg. 8433 (Jan. 20, 2025) (*Declaring a National Energy Emergency*), <https://www.whitehouse.gov/presidential-actions/2025/01/declaring-a-national-energy-emergency/>.

³⁵ *Id.*

³⁶ See also *Resource Adequacy Report: Evaluating the Reliability and Security of the United States Electric Grid*, U.S. Department of Energy (July 2025), at 1, <https://www.energy.gov/sites/default/files/2025-07/DOE%20Final%20EO%20Report%20%28FINAL%20JULY%207%29.pdf>.

³⁷ Ekku Jokinen, *Top 21 Artificial Intelligence Companies in Michigan*, (last accessed Aug. 13, 2025), <https://www.inven.ai/company-lists/top-21-artificial-intelligence-companies-in-michigan>.

³⁸ See *Michigan utility Consumers Energy to provide 1GW of power to new hyperscale data center*, Data Center Dynamics (August 05, 2025), <https://www.datacenterdynamics.com/en/news/michigan-utility-consumers-energy-to-provide-1gw-of-power-to-new-hyperscale-data-center/> (quoting Consumers Energy CEO Garrick Rochow).

changing characteristics of the electric generating fleet, inadequate transmission system infrastructure, growing pressures from extreme weather, and rapid load growth.”³⁹ Ms. Curran also described “much stronger growth [in demand for electricity] from continued electrification efforts, a resurgence in manufacturing, and an unexpected demand for energy-hungry data centers to support artificial intelligence.”⁴⁰ She added, “[a] growing reliability risk is that the rapid retirement of existing coal and gas power plants threatens to outpace the ability of new resources with the necessary operational characteristics to replace them.”⁴¹

ORDER

FPA section 202(c)(1) provides that whenever the Secretary of the Department of Energy determines “that an emergency exists by reason of a sudden increase in the demand for electric energy, or a shortage of electric energy or of facilities for the generation or transmission of electric energy,” then the Secretary has the authority “to require by order . . . such generation, delivery, interchange, or transmission of electric energy as in its judgment will best meet the emergency and serve the public interest.”⁴² This statutory language constitutes a specific grant of authority to the Secretary to require the continued operation of the Campbell Plant when the Secretary has determined that such continued operation will best meet an emergency caused by a sudden increase in the demand for electric energy or a shortage of generation capacity.

Such is the case here. As described above, the emergency conditions resulting from increasing demand and accelerated retirements of generation facilities supporting the issuance of Order No. 202-25-3 will continue in the near term and are also likely to continue in subsequent years. This could lead to the potential loss of power to homes and local businesses in the areas that may be affected by curtailments or outages, presenting a risk to public health and safety. Given the responsibility of MISO to identify and dispatch generation necessary to meet load requirements, I have determined that, under the conditions specified below, continued additional dispatch of the Campbell Plant is necessary to best meet the emergency and serve the public interest under FPA section 202(c).

To ensure the Campbell Plant will be available if needed to address emergency conditions, the Campbell Plant shall remain in operation until November 19, 2025.⁴³

³⁹ Keeping the Lights On: Examining the State of Regional Grid Reliability Before the House Committee on Energy and Commerce, Subcommittee on Energy, 119th Cong. (Mar. 25, 2025) (statement of Ms. Jennifer Curran, Senior Vice President for Planning and Operations, Midcontinent Independent System Operator), at 5, https://democrats-energycommerce.house.gov/sites/evo-subsites/democrats-energycommerce.house.gov/files/evo-media-document/witness-testimony_curran_eng_grid-operators_03.25.2025.pdf.

⁴⁰ *Id.* at 6.

⁴¹ *Id.* at 7.

⁴² Although the text of FPA section 202(c) grants this authority to “the Commission,” section 301(b) of the Department of Energy Organization Act transferred this authority to the Secretary of the Department of Energy. *See* 42 U.S.C. § 7151(b) (2018).

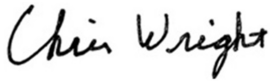
⁴³ 16 U.S.C. § 824a(c)(4).

Based on my determination of an emergency set forth above, I hereby order:

- A. From August 21, 2025, MISO and Consumer Energy shall take all measures necessary to ensure that the Campbell Plant is available to operate. For the duration of this Order, MISO is directed to take every step to employ economic dispatch of the Campbell Plant to minimize cost to ratepayers. Following the conclusion of this Order, sufficient time for orderly ramp down is permitted, consistent with industry practices. Consumers Energy is directed to comply with all orders from MISO related to the availability and dispatch of the Campbell Plant.
- B. To minimize adverse environmental impacts, this Order limits operation of dispatched units to the times and within the parameters as determined by MISO pursuant to paragraph A. MISO shall provide a daily notification to the Department (via AskCR@hq.doe.gov) reporting whether the Campbell Plant has operated in compliance with the allowances contained in this Order.
- C. All operation of the Campbell Plant must comply with applicable environmental requirements, including but not limited to monitoring, reporting, and recordkeeping requirements, to the maximum extent feasible while operating consistent with the emergency conditions. This Order does not provide relief from any obligation to pay fees or purchase offsets or allowances for emissions that occur during the emergency condition or to use other geographic or temporal flexibilities available to generators.
- D. By September 4, 2025, MISO is directed to provide the Department of Energy (via AskCR@hq.doe.gov) with information concerning the measures it has taken and is planning to take to ensure the operational availability of the Campbell Plant consistent with this Order. MISO shall also provide such additional information regarding the environmental impacts of this Order and its compliance with the conditions of this Order, in each case as requested by the Department of Energy from time to time.
- E. Consumers is directed to file with the Federal Energy Regulatory Commission Tariff revisions or waivers to effectuate this Order. Rate recovery is available pursuant to 16 U.S.C. § 824a(c).
- F. This Order shall not preclude the need for the Campbell Plant to comply with applicable state, local, or Federal law or regulations following the expiration of this Order.
- G. Because this Order is predicated on the shortage of facilities for generation of electric energy and other causes, the Campbell Plant shall not be considered a capacity resource.

H. This Order shall be effective from 00:00 Eastern Daylight Time (EDT) on August 21, 2025, and shall expire at 00:00 EDT on November 19, 2025, with the exception of applicable compliance obligations in paragraph D.

I. Issued in Norfolk, Virginia at 8:50pm Eastern Daylight Time on this 20th day of August 2025.



Chris Wright
Secretary of Energy

cc: **FERC Commissioners**
Chairman David Rosner
Commissioner Lindsay S. See
Commissioner Judy W. Chang

Michigan Public Service Commissioners
Chairman Dan Scripps
Commissioner Katherine Peretick
Commissioner Shaquila Myers

EXHIBIT E

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 85, 86, 600, 1036, 1037, and 1039

[EPA-HQ-OAR-2025-0194; FRL-12715-01-OAR]

RIN 2060-AW71

Reconsideration of 2009 Endangerment Finding and Greenhouse Gas Vehicle Standards

AGENCY: Environmental Protection Agency (EPA).

ACTION: Proposed rule.

SUMMARY: In this action, the U.S. Environmental Protection Agency (EPA) is proposing to repeal all greenhouse gas (GHG) emission standards for light-duty, medium-duty, and heavy-duty vehicles and engines to effectuate the best reading of Clean Air Act (CAA) section 202(a). We propose that CAA section 202(a) does not authorize the EPA to prescribe emission standards to address global climate change concerns and, on that basis, propose to rescind the Administrator's prior findings in 2009 that GHG emissions from new motor vehicles and engines contribute to air pollution which may endanger public health or welfare. We further propose, in the alternative, to rescind the Administrator's prior findings in 2009 because the EPA unreasonably analyzed the scientific record and because developments cast significant doubt on the reliability of the findings. Lastly, we propose to repeal all GHG emission standards on the alternative bases that no requisite technology for vehicle and engine emission control can address the global climate change concerns identified in the findings without risking greater harms to public health and welfare.

DATES:

Comments. Comments must be received on or before September 15, 2025. Comments on the information collection provisions submitted to the Office of Management and Budget (OMB) under the Paperwork Reduction Act (PRA) are best assured of consideration by OMB if OMB receives a copy of your comments on or before September 2, 2025.

Public Hearing. The EPA will announce information regarding the public hearing for this proposal in a supplemental **Federal Register** document. Please refer to the **SUPPLEMENTARY INFORMATION** section for additional information on the public hearing.

ADDRESSES: *Comments.* You may send comments, identified by Docket ID No. EPA-HQ-OAR-2025-0194, by any of the following methods:

- *Federal eRulemaking Portal:* <https://www.regulations.gov/> (our preferred method). Follow the online instructions for submitting comments.
- *Email:* a-and-r-Docket@epa.gov. Include Docket ID No. EPA-HQ-OAR-2025-0194 in the subject line of the message.
- *Mail:* U.S. Environmental Protection Agency, EPA Docket Center, OAR Docket, Mail Code 28221T, 1200 Pennsylvania Avenue NW, Washington, DC 20460.
- *Hand Delivery or Courier:* EPA Docket Center, WJC West Building, Room 3334, 1301 Constitution Avenue NW, Washington, DC 20004. The Docket Center's hours of operations are 8:30 a.m.–4:30 p.m., Monday–Friday (except Federal Holidays).

Instructions. All submissions received must include the Docket ID No. for this rulemaking. Comments received may be posted without change to <https://www.regulations.gov/>, including any personal information provided. For detailed instructions on sending comments and additional information on the rulemaking process, see the “Public Participation” heading of the **SUPPLEMENTARY INFORMATION** section of this document.

FOR FURTHER INFORMATION CONTACT:

Alan Stout, Assessment and Standards Division, Office of Transportation and Air Quality, Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; telephone number: (734) 214-4805; email address: stout.alan@epa.gov.

SUPPLEMENTARY INFORMATION:

A. Public Participation

Written Comments. Submit your comments, identified by Docket ID No. EPA-HQ-OAR-2025-0194, at <https://www.regulations.gov/> (our preferred method), or the other methods identified in the **ADDRESSES** section. Once submitted, comments cannot be edited or removed from the docket. The EPA may publish any comment received to its public docket. Do not submit to the EPA's docket at <https://www.regulations.gov/> any information you consider to be Confidential Business Information (CBI), Proprietary Business Information (PBI), or other information whose disclosure is restricted by statute. If you choose to submit CBI or PBI as a comment to the EPA's docket, please send those materials to the person listed in the **FOR FURTHER INFORMATION CONTACT** section.

Multimedia submissions (audio, video, etc.) must be accompanied by a written comment. The written comment is considered an official comment and should include discussion of all points you wish to make. The EPA will generally not consider comments or comment contents located outside of the primary submission (i.e., on the web, cloud, or other file sharing system). Please visit <https://www.epa.gov/dockets/commenting-epa-dockets> for additional submission methods; the full EPA public comment policy; information about CBI, PBI, or multimedia submissions; and general guidance on making effective comments.

To facilitate comment on the portions of the rule on which the EPA is specifically soliciting comment, the EPA has indexed each comment solicitation with a unique identifier (e.g., “C-1”, “C-2”) in section VII of this preamble to provide a consistent framework for effective and efficient provision of comments. Accordingly, we ask that commenters include the corresponding identifier when providing comments relevant to that comment solicitation. We ask that commenters include the identifier either in a heading or within the text of each comment, to make clear which comment solicitation is being addressed. We note that we are not limiting comment to these identified areas.

Participation in Virtual Public Hearing. The EPA will announce information regarding the public hearing for this proposal in a supplemental document in the **Federal Register**. The hearing notice, registration information, and any updates to the hearing schedule will also be available at <https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-reconsideration-2009-endangerment-finding>. Please refer to this website for any updates regarding the hearings. The EPA does not intend to publish additional documents in the **Federal Register** announcing updates to the hearing schedule.

Docket. All documents in the docket are listed on the www.regulations.gov website. Although listed in the index, some information is not publicly available, e.g., CBI or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, is not placed on the internet and will be publicly available only in hard copy form through the EPA Docket Center at the location listed in the **ADDRESSES** section of this document.

B. Action Applicability

This action relates to companies that manufacture, sell, or import into the

United States light-, medium-, or heavy-duty motor vehicles and engines.

Potentially affected categories and entities include the following:

NAICS code ^a	NAICS title
336110	Automobile and Light-duty Motor Vehicle Manufacturing.
336120	Heavy Duty Truck Manufacturing.
336211	Motor Vehicle Body Manufacturing.
336213	Motor Home Manufacturing.
336310	Motor Vehicle Gasoline Engine and Engine Parts Manufacturing.
336390	Other Motor Vehicle Parts Manufacturing.
333618	Other Engine Equipment Manufacturing.
423110	Automobile and Other Motor Vehicle Merchant Wholesalers.
811198	All Other Automotive Repair and Maintenance.

^a NAICS Association. NAICS & SIC Identification Tools. Available online: <https://www.naics.com/search>.

This table is not intended to be exhaustive but rather provides a guide for readers regarding entities potentially affected by this action. This table lists the types of entities that the EPA is presently aware could potentially be affected by this action. Other types of entities not listed in the table could also be affected. To determine whether your entity is regulated by this action, you should carefully examine the applicability criteria found in Code of Federal Regulations (CFR) title 40, parts 85, 86, 600, 1036, and 1037. If you have questions regarding the applicability of this action to a particular entity, consult the person listed in the **FOR FURTHER INFORMATION CONTACT** section.

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I. Executive Summary**A. Introduction**

In this action, the EPA proposes to rescind all greenhouse gas (GHG) emission standards for light-duty, medium-duty, and heavy-duty vehicles and engines under CAA section 202(a). Upon review of the underlying actions and intervening legal and scientific developments, including recent decisions by the U.S. Supreme Court and the scientific information summarized in this preamble, the EPA no longer believes that we have the statutory authority and record basis required to maintain this novel and transformative regulatory program. We seek comment on all aspects of this proposal, including on the legal and scientific developments that are being subject to public comment for the first time in this rulemaking.

In 2009, the EPA took the unprecedented step of asserting authority to regulate GHG emissions in a standalone action titled "Endangerment and Cause or Contribute Finding for Greenhouse Gases Under Section 202(a) of the Clean Air Act," 74 FR 66496 (Dec. 15, 2009) (Endangerment Finding). In that action, we interpreted CAA section 202(a) for the first time to authorize regulation of domestic emissions from new motor vehicles and engines based on global climate change concerns rather than air pollution that endangers public health or welfare through local or regional exposure. 74 FR 66526–27. We also asserted that because the statute is "silent on [the] issue," CAA section 202(a) grants "procedural discretion" to issue standalone findings that trigger a duty to regulate without considering the standards that must issue in response.

74 FR 66501–02. The Administrator exercised this newfound discretion to make separate findings that elevated global concentrations in the upper atmosphere of six “well-mixed GHGs”—carbon dioxide (CO₂), methane, nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆)—constitute “air pollution” that may reasonably be anticipated to endanger public health and welfare, 74 FR 66516–36, and that GHG emissions from all potential classes of motor vehicles and engines contribute to such elevated global concentrations of GHGs in the upper atmosphere and therefore to air pollution that endangers public health and welfare, 74 FR 66536–45.

With respect to endangerment, the Administrator found that global concentrations of GHGs from all foreign and domestic sources “constitute the largest anthropogenic driver of climate change” and attributed climate change impacts to global GHG concentrations. 74 FR 66517. Next, the Administrator summarized literature reviews finding that climate change “can increase the risk of morbidity and mortality” indirectly through increased global temperature, air quality effects, and changes in extreme weather events and can impact welfare indirectly through net impacts on food production, forestry, water resources, sea level rise, energy infrastructure, and ecosystems. 74 FR 66522–35. On that basis, the Administrator found that global concentrations of GHGs constitute “air pollution” that endangers public health and welfare. 74 FR 66516. For purposes of this preamble, we use the phrase global climate change concerns to refer to the risks the Administrator associated with climate change in 2009.

With respect to causation or contribution, the Administrator used emissions data for existing motor vehicles and engines to project that all potential classes of new motor vehicles and engines would emit four GHGs—CO₂, methane, N₂O, and HFCs—that would collectively amount to 4.3 percent of global GHG emissions. 74 FR 66543. The Administrator acknowledged that more would usually be required to support contribution “when addressing a more typical local or regional air pollution problem.” 74 FR 66539. Nevertheless, asserting discretion to interpret the ambiguous term “contribute,” the Administrator found that the “unique” nature of global climate change meant that “contributors must do their part even if their contributions to the global climate change problem, measured in terms of percentage, are smaller than typically

encountered when tackling solely regional or local environmental issues.” 74 FR 66542–43.

The EPA subsequently relied on the Endangerment Finding to impose increasingly stringent GHG emission standards for new motor vehicles and engines and to attempt, largely without success, to extend its GHG initiative into additional CAA programs. In *Utility Air Regulatory Group v. EPA*, 573 U.S. 302 (2014) (*UARG*), the Supreme Court rejected our attempt to extend GHG emission standards to stationary sources subject to Title I and Title V requirements, including after we admitted that applying the statutory scheme as written to GHG emissions from most covered stationary sources would be unworkable. And in *West Virginia v. EPA*, 597 U.S. 697 (2022), the Court vacated our attempt to shift the power grid away from using fossil fuels through GHG standards for existing power plants under CAA section 111(d). The Court held in both cases that the agency actions at issue implicated the major questions doctrine, and that Congress must clearly authorize agencies to take actions that decide major questions of policy. Nevertheless, the EPA continued to retain and expand GHG emission standards for new motor vehicles and engines that impose billions of dollars in compliance costs on American businesses and consumers. Meanwhile, global GHG concentrations in the upper atmosphere have continued to rise, driven primarily by increased emissions from foreign sources,¹ all without producing the degree of adverse impacts to public health and welfare in the United States that the EPA anticipated in the 2009 Endangerment Finding.

The EPA now proposes to rescind the Endangerment Finding and all resulting GHG emission standards for new motor vehicles and engines, including the light-duty, medium-duty, and heavy-duty vehicle and engine standards for model years (MY) 2012 to 2027 and beyond. The remainder of this section describes the need for regulatory action and the scope of the proposed action, including rescission of the Endangerment Finding, repeal of related GHG emission standards, and minor conforming adjustments to unrelated emission standards for new motor vehicles and engines that we are not proposing to alter as part of this rulemaking.

Section II of this preamble sets out relevant background, including the

events leading up to the Endangerment Finding, the approach taken in the Endangerment Finding to analyzing the scientific record, and the regulations issued since 2009 in reliance on the Endangerment Finding. We also summarize the premises, assumptions, and conclusions in the Endangerment Finding and the scientific information, including empirical data, peer-reviewed studies, and real-world developments since 2009 that led the Administrator to develop concerns sufficient to initiate reconsideration of the ongoing validity and reliability of the Endangerment Finding.

Section III of this preamble describes our legal authority to rescind the Endangerment Finding and repeal the resulting GHG standards issued under CAA section 202(a). Because this proposed action would not impact fuel economy standards and emission standards for criteria pollutants and hazardous air pollutants regulated under the CAA, we explain the relationship between these regulations to set the outer bounds of amendments at issue in this rulemaking.

Section IV.A of this preamble describes our proposal to rescind these prior actions because the Endangerment Finding exceeded our statutory authority under CAA section 202(a). As explained further below, we propose that the term “air pollution” as used in CAA section 202(a) is best read in context as referring to local or regional exposure to dangerous air pollution, consistent with our longstanding practice before 2009. We further propose that CAA section 202(a) does not grant the Administrator “procedural discretion” to issue standalone findings that trigger a duty to regulate, or, conversely, to prescribe standards, without making the requisite findings for the particular air pollutant emissions and class or classes of new motor vehicles or engines at issue. We also propose that CAA section 202(a) does not authorize the Administrator to make separate findings for endangerment and causation or contribution. Rather, we propose that CAA section 202(a) requires the Administrator to find that the relevant air pollutant emissions from the class or classes of new motor vehicles or engines at issue cause, or contribute to, air pollution which endangers public health or welfare, without relying on emissions from stationary or other sources regulated by distinct CAA provisions. As the Supreme Court made clear in *Loper Bright Enterprises v. Raimondo*, 603 U.S. 369 (2024), we can no longer rely on statutory silence or ambiguity to expand our regulatory power. And

¹ Crippa, M. et al. (2023). GHG emissions of all world countries. Publications Office of the European Union: <https://doi.org/10.2760/953322>.

because the Nation's response to global climate change concerns is an issue of significant importance that Congress did not clearly address in CAA section 202(a), we propose that the major questions doctrine further reinforces and provides an additional basis for our proposed interpretations and actions. The Agency did not have the benefit of the Court's decisions in *Loper Bright* and *West Virginia*, among other applicable precedents, when issuing the Endangerment Finding in 2009. Finally, we explain that the EPA reached contrary conclusions in the Endangerment Finding by misconstruing the Supreme Court's decision in *Massachusetts v. EPA*, 549 U.S. 497 (2007), which vacated our denial of a petition for rulemaking on distinct grounds. Read on its own terms, *Massachusetts* did not require the Agency to find that GHGs are subject to regulation under CAA section 202(a) and does not support our implementation of the statute since 2009.

Section IV.B of this preamble describes our alternative proposal to rescind these prior actions even if CAA section 202(a) authorizes the EPA to address GHG emissions based on global climate change concerns by concluding that the Administrator exercised that authority unreasonably in the Endangerment Finding. Specifically, we propose that the EPA misapplied the statutory standard for regulation to the scientific record by severing the analysis into separate parts without considering whether all parts of the analysis, taken as a whole, supported the findings and regulatory determinations required by the statute. We further propose that empirical data, peer-reviewed studies, and real-world developments since 2009 have cast significant doubt on many of the critical premises, assumptions, and conclusions in the Endangerment Finding such that it would be unreasonable to retain the decision and the resulting regulatory framework. In proposing this alternative, we note that the Supreme Court has continued to emphasize that agencies have significant discretion when making complex judgments within the bounds of an authorizing statute.² We propose that the Administrator may now exercise the

discretion expressly delegated to him by Congress in the text of CAA section 202(a) by rescinding the Endangerment Finding.

Section V of this preamble proposes additional bases for repealing the EPA's GHG emission standards for new motor vehicles and engines under CAA section 202(a) even if the Endangerment Finding were to remain in place. We propose that there is no "requisite technology" responsive to the global climate change concerns identified in the Endangerment Finding given evidence that reducing GHG emissions from new motor vehicles and engines to zero would not have a scientifically measurable impact on global GHG concentrations and climate trends. We also propose that, on balance, and contrary to the core objectives of CAA section 202(a), GHG emission standards harm public health and welfare by increasing prices, decreasing consumer choice, and slowing the replacement of older vehicles that are less safe and emit a greater volume and variety of air pollutants than new motor vehicles and engines.

Section VI of this preamble details the scope of the proposed repeal, including its relationship to distinct regulatory programs and federal preemption, the revisions to 40 CFR parts 85, 86, 600, 1036, 1037, and 1039 required to effectuate repeal of all GHG emission standards, and conforming adjustments to regulatory provisions that we are not proposing to reopen or substantively revise. Specifically, in this NPRM we are not proposing to change at this time elements of the regulations that are necessary for programs unrelated to the Endangerment Finding, including emission standards for criteria pollutants and air hazards and the EPA's statutory role in vehicle standards administered by the National Highway Traffic Safety Administration (NHTSA).

Section VII of this preamble specifically requests comment on key aspects of this proposed action and indexes comment solicitation to promote public participation and facilitate our review of public comments. Note that we are not limiting public participation to the issues raised in this section and will respond to all comments within the scope of this proposal. Rather, we are highlighting aspects of the proposal for which public input would be particularly helpful in determining whether and in what respects to finalize this proposed action.

B. Need for Regulatory Action

Immediately upon taking office, President Trump established new Executive Branch priorities for energy,

transportation, and consumer choice and committed to ensuring regulations remain within constitutional and statutory bounds. On January 20, 2025, the President issued an Executive Order titled "Unleashing American Energy" to address the burdens placed by unnecessary regulations on energy affordability, job creation, and national security.³ As relevant here, the President directed the EPA Administrator to submit recommendations to the Director of OMB on the legality and continuing applicability of the 2009 Endangerment Finding.⁴ On February 19, 2025, the President issued an Executive Order titled "Ensuring Lawful Governance and Implementing the President's 'Department of Government Efficiency' Deregulatory Initiative" that further instructed agencies, including the EPA, to review existing regulations for consistency with the Constitution and the best reading of the authorizing statute.⁵

Upon confirmation by the Senate, Administrator Lee Zeldin committed the EPA to prioritizing its core statutory mission and ensuring that all regulatory actions are clearly grounded in statutory authority and the best reading of the law. As part of these efforts, and consistent with the "Unleashing American Energy" Executive Order, the Administrator initiated a review of the legality and applicability of the Endangerment Finding. On February 19, 2025, the Administrator submitted a memorandum to the OMB Director recommending that the EPA reconsider the Endangerment Finding to address legal and scientific developments that appear to undermine the bases for that action and subsequent regulations.⁶ The Administrator noted that recent Supreme Court decisions, including *Loper Bright*, *West Virginia*, *UARG*, and *Michigan v. EPA*, 576 U.S. 743 (2015), provided new guidance on how we should interpret and apply the statutes Congress entrusted us to administer.⁷ The Administrator further noted that the Endangerment Finding recognized significant uncertainties in its conclusions and assumptions that should be evaluated in light of more recent empirical data and scientific

³ Executive Order 14154, 90 FR 8353 (Jan. 29, 2025).

⁴ *Id.* § 6(f).

⁵ Executive Order 14219, 90 FR 10583 (Feb. 25, 2025).

⁶ Memorandum from Lee Zeldin, Administrator, Environmental Protection Agency, to Russell Vought, Director, Office of Management and Budget (Feb. 19, 2025) (Feb. 19, 2025 Memo), available in the docket for this rulemaking.

⁷ *Id.* at 1.

² *Seven Cnty. Infrastructure Coal. v. Eagle Cnty.*, 145 S. Ct. 1497, 1511–15 (2025); *FDA v. Wages & White Lion Invs., L.L.C.*, 145 S. Ct. 898, 917 (2025); *Baltimore Gas & Elec. Co. v. NRDC, Inc.*, 462 U.S. 87, 103 (1983); see also *Huntsman Petrochemical LLC v. EPA*, 114 F.4th 727, 735 (D.C. Cir. 2024) ("In the case of EPA's evaluation of scientific data within its area of expertise, [courts] accord an extreme degree of deference." (quotation marks omitted)).

evidence.⁸ Accordingly, the Administrator announced on March 12, 2025, that the EPA would reconsider the Endangerment Finding and subsequent actions to determine whether our GHG regulations have an adequate statutory basis and to seek public input on developments since 2009.⁹

As part of this reconsideration, the EPA closely examined applicable law, including judicial precedents and interpretive aids bearing on the meaning of CAA section 202(a) and related statutory provisions. We also reviewed actions taken to regulate GHG emissions from new motor vehicles and new motor vehicle engines since 2009, assessed the costs and non-cost adverse impacts of these GHG emission standards, and evaluated the effectiveness of these GHG emission standards in reducing the dangers identified in the Endangerment Finding, that is, in mitigating the impacts anticipated to result from elevated global GHG concentrations in the upper atmosphere.

Furthermore, the Administrator reviewed available information, including the most recently available science, bearing on the assumptions and conclusions in the Endangerment Finding, the impacts of global GHG concentrations on public health and welfare in the United States, and the relative contribution of domestic emissions from new motor vehicles and engines to global GHG concentrations. As part of that review, the Administrator received and evaluated the draft report submitted by the U.S. Department of Energy (DOE) Climate Working Group (CWG) to Secretary of Energy Christopher Wright on May 27, 2025, titled “Impacts of Carbon Dioxide Emissions on the U.S. Climate” (2025 CWG Draft Report). The 2025 CWG Draft Report analyzes empirical data, peer-reviewed studies, and available scientific information bearing on direct human influence on ecosystems and climate, climate response to CO₂ emissions, and impacts on ecosystems and society.¹⁰ The Administrator also

considered available assessments by the U.S. Government and relevant international bodies, including the Third, Fourth, and Fifth National Climate Assessments (NCAs) reported by the U.S. Global Change Research Program (USGCRP)¹¹ and the Fifth Assessment Report (AR5) and Sixth Assessment Report (AR6) by the United Nations Intergovernmental Panel on Climate Change (IPCC).¹² As discussed in section IV.B of this preamble, the Administrator also considered critiques of the NCAs, and the Fifth NCA in particular, and reviewed these analyses for consistency with OMB information quality guidelines¹³ and the transparency and reliability requirements of Executive Order 14303, “Restoring Gold Standard Science.”¹⁴

The Administrator’s review of the relevant information, including scientific literature, gave rise to serious concerns that our actions taken to regulate GHG emissions from new motor vehicles and engines exceed our statutory authority under CAA section 202(a) and are otherwise inappropriate. Continuing to impose billions of dollars in regulatory costs on American businesses and consumers without an adequate legal basis would threaten to undermine public confidence in our activities and commitment to fulfilling the Agency’s core mission: protecting human health and the environment. The EPA has expended significant resources implementing the GHG regulatory program for mobile sources and attempting to expand its GHG regulatory program to stationary sources with limited success in the courts and no apparent real-world results, often at the expense of programs that fall squarely within our statutory authority. Prompt

efforts through the docket available at <https://www.energy.gov/topics/climate>.

¹¹ Created by the Global Change Research Act of 1990, Public Law 101–606, 104 Stat. 3096, the USGCRP reports an NCA at least every four years to Congress and the President that must (1) integrate, evaluate, and interpret the findings of the Program and discuss the scientific uncertainties with such findings; (2) analyze the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, human health and welfare, human social systems, and biological diversity; and (3) analyze current trends in global change, both human-induced and natural, and project major trends for the subsequent 25 to 100 years. See 15 U.S.C. 2936.

¹² The IPCC invites participation by members of the United Nations and World Meteorological Organization and summarizes available literature on climate science but does not conduct its own research. See United Nations Intergovernmental Panel on Climate Change, About the IPCC, available online at <https://www.ipcc.ch/about/>.

¹³ “Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by Federal Agencies; Republication,” 67 FR 8452 (Feb. 22, 2002).

¹⁴ 90 FR 22601 (May 29, 2025).

action is needed to address these concerns with the benefit of public participation.

Relatedly, the Administrator has serious concerns that many of the scientific underpinnings of the Endangerment Finding are materially weaker than previously believed and contradicted by empirical data, peer-reviewed studies, and scientific developments since 2009. This proposal seeks public comment on these developments for the first time. Prompt action is needed to address these concerns, and the Administrator requests stakeholder input on the continuing vitality of the assumptions, predictions, and conclusions animating the Endangerment Finding.

C. Summary of the Major Provisions in This Proposed Action

If finalized, this action would rescind the 2009 Endangerment Finding for GHGs emitted by new motor vehicles and new motor vehicle engines under CAA section 202(a) (74 FR 66496). If finalized, this action would also rescind denials of petitions for reconsideration of the Endangerment Finding in 2022 and 2010 entitled “Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act; Final Action on Petitions,” 87 FR 25412 (Apr. 29, 2022), and “EPA’s Denial of the Petitions to Reconsider the Endangerment and Cause or Contribute Finding for Greenhouse Gases Under Section 202(a) of the Clean Air Act,” 75 FR 49556 (Aug. 13, 2010).¹⁵ Although the 2022 and 2010 petition denials have no prospective legal effect, we propose to rescind them for the sake of consistency and to ameliorate potential confusion regarding the EPA’s proposed action. As explained later in this preamble, the denials reflect many of the same legal and scientific flaws we propose to correct by rescinding the Endangerment Finding. We seek comment on the impact of the denials, if any, and on whether the denials were legally flawed for additional reasons not explicitly explored in this proposal. In addition, as a result of these proposed changes, we would no longer have a basis for issuing or retaining GHG emission standards for new motor vehicles and new motor vehicle engines, including

¹⁵ The 2022 petition denials included a notice of decision in the **Federal Register** (87 FR 25412), brief letters communicating the denials to the petitioners, and a decision document entitled “EPA’s Denial of Petitions Relating to the Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act” (Apr. 21, 2022) (2022 Denial), available online at https://www.epa.gov/system/files/documents/2022-04/decision_document.pdf.

⁸ *Id.* at 8.

⁹ “Trump EPA Kicks Off Formal Reconsideration of Endangerment Finding with Agency Partners” (Mar. 12, 2025), available at <https://www.epa.gov/newsreleases/trump-epa-kicks-formal-reconsideration-endangerment-finding-agency-partners>.

¹⁰ The 2025 CWG Draft Report was provided to the EPA on May 27, 2025, and was reviewed and relied upon in formulating this proposal. The EPA understands that DOE is releasing an updated version of the CWG draft report and seeking public comment on the updated report, which includes additional information and typographical corrections that the EPA did not rely upon in formulating this proposal. Interested parties may review and comment on the updated version of the CWG draft report for consideration as part of DOE’s

for MYs that have completed manufacture but are subject to ongoing obligations. As discussed elsewhere in this preamble, the EPA is reconsidering additional endangerment findings and GHG emission standards issued under distinct provisions of the CAA in separate rulemakings and is not reopening or proposing to modify those additional findings and standards in this proceeding.

In connection with the proposed rescission of the Endangerment Finding, if finalized, this action would remove all existing regulations that require new motor vehicle and new motor vehicle engine manufacturers to measure, report, or comply with GHG emission standards. Specifically, the EPA proposes to remove regulations in 40 CFR parts 85, 86, 600, 1036, and 1037 pertaining to the control of GHG emissions from light-, medium-, and heavy-duty vehicles and engines, including emission standards, test procedures, averaging, banking, and trading requirements (ABT), reporting requirements, and fleet-average emission requirements.¹⁶ As a result of these proposed changes, motor vehicle and engine manufacturers would no longer have future or current obligations for the measurement, control, or reporting of GHG emissions for any vehicle or engine, including for previously manufactured MYs. However, we are not proposing to reopen or modify any regulations necessary for criteria pollutant and air toxic measurement and standards, Corporate Average Fuel Economy (CAFE) testing, and associated fuel economy labeling requirements. We seek comment on whether any elements of the regulations, test procedures, or GHG emission models that are proposed for removal should remain to support programs unrelated to the GHG

emission standards and why the preservation of such an element is necessary to support the unrelated program or programs.

II. Background

A. The EPA's Historical Approach to CAA Section 202(a)

Congress originally enacted the language that became CAA section 202(a) as part of the Motor Vehicle Pollution Control Act of 1965, which required the Secretary of Health, Education, and Welfare to “prescribe . . . standards, applicable to the emission of any kind of substance, from any class or classes of new motor vehicles or new motor vehicle engines, which in his judgment cause or contribute to, or are likely to cause or contribute to, air pollution which endangers the health or welfare of any persons.”¹⁷ Congress retained this language, while adding additional requirements for the content of emission standards, in the Air Quality Act of 1967,¹⁸ and, later, incorporated it into the Clean Air Act of 1970, which transferred the Secretary's regulatory authority to the newly created EPA.¹⁹ Separately, the 1970 CAA addressed emissions from existing vehicles and engines, stationary sources, and aircraft engines.²⁰ As subsequently amended, CAA section 202(a) has remained a critical part of the comprehensive national framework for regulating air pollution from mobile sources, and new motor vehicles and new motor vehicle engines in particular, under Title II of the CAA.²¹

In its first four decades administering the statute, the EPA applied CAA section 202(a) to local and regional air pollution problems through rulemakings that prescribed standards and set forth the Administrator's findings that the relevant air pollutant emissions cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.²² As explained in the following subsections, the EPA maintained this approach through 2008 and never sought to invoke CAA section 202(a) to regulate in

response to global climate change concerns.

B. Petitions for Rulemaking and *Massachusetts v. EPA*

In October 1999, a coalition of 19 environmental organizations petitioned the EPA to regulate the emission of four GHGs—CO₂, methane, N₂O, and HFCs—from new motor vehicles and engines under CAA section 202(a)(1). Petitioners claimed that these four GHGs were “air pollutant[s]” under CAA section 302(g), significantly contributed to global climate change, and met the statutory standard for regulation under CAA section 202(a)(1). Thus, petitioners claimed that the EPA had the authority and obligation to find that GHG emissions from new motor vehicles and engines cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare and to prescribe standards in response.

In September 2003, after receiving and responding to nearly 50,000 public comments on the relevant issues, the EPA denied the 1999 petitions in a final action titled “Control of Emissions from New Highway Vehicles and Engines,” 68 FR 52922 (Sept. 8, 2003) (2003 Denial). The 2003 Denial asserted three primary reasons for denying the petitions. First, after “examin[ing] the fundamental issue of whether the CAA authorizes the imposition of control requirements” to “reduce the risk of global climate change,” we concluded that “CO₂ and other GHGs cannot be considered ‘air pollutants’ subject to the CAA’s regulatory provisions for any contribution they may make to global climate change.” 68 FR 52925. Citing the Supreme Court’s decision in *FDA v. Brown & Williamson Tobacco Corp.*, 529 U.S. 120 (2000), we noted that the CAA does not address GHGs as a regulatory matter, including in recent amendments, and that “EPA has used these provisions to address air pollution problems that occur primarily at ground level or near the surface of the earth.” 68 FR 52926. On this basis, we concluded that GHGs “are not air pollutants under the CAA’s regulatory provisions, including sections 108, 109, 111, 112, and 202” because they categorically are not “air pollutant[s]” under the Act-wide definition in CAA section 302(g). 68 FR 52928. Second, we concluded that regulating GHG emissions from motor vehicles and engines under the CAA would interfere with NHTSA’s separate authority to implement fuel economy standards. 68 FR 52929. Finally, we asserted that regulating GHG emissions from motor vehicle engines under the CAA would

¹⁶ “Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards,” 75 FR 25324 (May 7, 2010); “Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles,” 76 FR 57106 (Sept. 15, 2011); “2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards,” 77 FR 62624 (Oct. 15, 2012); “Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles-Phase 2,” 81 FR 73478 (Oct. 25, 2016); “The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks,” 85 FR 24174 (Apr. 30, 2020); “Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards,” 86 FR 74434 (Dec. 30, 2021); “Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles,” 89 FR 27842 (Apr. 18, 2024); “Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles-Phase 3,” 89 FR 29440 (Apr. 22, 2024).

¹⁷ Public Law 89–272, 202(a), 79 Stat. 992, 992–93 (1965).

¹⁸ Public Law 90–148, 202(a), 81 Stat. 485, 499 (1967).

¹⁹ Public Law 91–604, 84 Stat. 1690 (1970).

²⁰ *Id.*

²¹ In the Clean Air Act Amendments of 1977, Congress replaced the phrase “which endangers the public health or welfare” with “which may reasonably be anticipated to endanger public health or welfare.” Public Law 95–95, 401(d)(1), 91 Stat. 685, 791 (1977).

²² See 74 FR 66501, 66527, 66538, 66543 (acknowledging this regulatory history).

undermine the President's overall policy approach of addressing global climate change through voluntary actions and incentives, the promotion of further research and technologies, and international negotiations. 68 FR 52930–31.

In *Massachusetts*, the Supreme Court narrowly reversed the D.C. Circuit's decision to uphold the EPA's denial of the 1999 petitions for rulemaking.²³ The Court took particular issue with the EPA's reading of the Act-wide definition in CAA section 302(g), ruling that “[t]he Clean Air Act’s sweeping definition of ‘air pollutant’ . . . embraces all airborne compounds of whatever stripe” and provided no textual basis for excluding CO₂ or the three other GHGs raised in the petitions for rulemaking. 549 U.S. at 528–29. The Court also addressed EPA's reliance on *Brown & Williamson*, which the majority construed as having found no congressional intent to ban the sale of tobacco products outright because such an application of the relevant statute would have been highly unlikely and because the Food and Drug Administration (FDA) had expressly refused to assert such authority in the past. *Id.* at 530–31. In contrast, in *Massachusetts*, the Court found that the CAA did not reflect a congressional intent to categorically exclude GHGs and, citing several Agency memoranda, that we had not similarly foresworn all authority to regulate GHGs as a categorical matter. *Id.* Notably, the Court expressly declined to decide whether the EPA was required to issue an affirmative endangerment finding as to GHG emissions under the standard set out in CAA section 202(a). *Id.* at 534 (“We need not and do not reach the question whether on remand EPA must make an endangerment finding.”). Nor did the Court address “whether policy concerns can inform EPA’s actions in the event that it makes such a finding.” *Id.* at 534–35. Rather, the Court held that we must respond to the petitions by deciding whether GHG emissions from new motor vehicles and engines meet the standard for regulation in CAA section 202(a) or whether the science was too uncertain to make any determination, and that, in doing so, we

must “ground [our] reasons for action or inaction in the statute.” *Id.* at 535.²⁴

C. The 2009 Endangerment Finding

The EPA responded to the Supreme Court's decision in *Massachusetts* by issuing an advanced notice of proposed rulemaking titled “Regulating Greenhouse Gas Emissions Under the Clean Air Act,” 73 FR 44354 (July 30, 2008) (2008 ANPRM). The Administrator began by noting it was “clear that if EPA were to regulate [GHG] emissions from motor vehicles under the Clean Air Act,” the interplay between CAA section 202(a) and similarly worded statutory provisions “could result in an unprecedented expansion of EPA authority that would have a profound effect on virtually every sector of the economy and touch every household in the land.” 73 FR 44355. The Administrator cautioned that because the CAA was “originally enacted to control regional pollutants that cause direct health effects,” invoking authority to regulate GHG emissions “would inevitably result in a very complicated, time-consuming, and, likely, convoluted set of regulations” that “would be relatively ineffective at reducing [GHG] concentrations” and have a “potentially damaging effect on jobs and the U.S. economy.” *Id.*

The 2008 ANPRM echoed the Administrator's concerns by seeking public comment on invoking CAA section 202(a) to regulate new motor vehicle and engine emissions in response to global climate change concerns. We acknowledged that the CAA “was not specifically designed to address GHGs,” 73 FR 44397, and that the EPA had historically interpreted and applied its CAA regulatory authorities to address local and regional air pollution, 73 FR 44408. We further noted that Congress was considering legislation to address the Nation's response to global climate change concerns and that, since *Massachusetts*, Congress had passed and the President had signed into law the Energy Independence and Security Act (EISA), which amended provisions applicable to the EPA's Renewable Fuels Standard

(RFS) program and NHTSA's CAFE standards program. 73 FR 44398. Finally, we noted that the EPA had received additional petitions to regulate stationary sources and additional GHGs, including water vapor, all of which suggested that GHG emission regulations could not readily be limited to new motor vehicles and engines. 73 FR 44399 & n.26.

As to CAA section 202(a), the 2008 ANPRM set out a framework for determining whether “GHG emissions from new motor vehicles cause or contribute to air pollution that may reasonably be anticipated to endanger public welfare” under CAA section 202(a)(1) or for “explain[ing] why scientific uncertainty is so profound that it prevents making a reasoned judgment on such a determination.” 73 FR 44398, 44421. We reviewed available information for CO₂, methane, and N₂O emissions and noted that HFCs, PFCs, and SF₆ are “often grouped together” and separately from the rest “because they contain fluorine, typically have large global warming potentials, and are produced only through human activities.” 73 FR 44401–02.²⁵ With respect to endangerment, we sought comment on whether GHGs could properly be considered dangerous air pollution because the potential health effects are indirect and the potential welfare effects may be positive on balance. 73 FR 44427. In addition, we sought comment on whether “the unique characteristics and properties of each GHG . . . as well as current and projected emissions” meant that each GHG should be analyzed individually or whether certain GHGs other than CO₂ were amenable to grouping. 73 FR 44428. With respect to causation or contribution, we presented motor vehicle and engine emissions data for each GHG separately and noted that emission trends had diverged between pollutants, with CO₂ emissions, for example, generally increasing since 1990 and N₂O emissions, for example, increasing from 1990 to 1995 and then falling substantially from 1995 to 2006 because of fuel and technology changes. 73 FR 44430. We also presented extensive information on potential regulatory approaches that could be triggered by a positive finding under CAA section 202(a), including

²³ The D.C. Circuit majority had upheld the denial on the merits because “the EPA Administrator properly exercised his discretion under § 202(a)(1) in denying the petition for rulemaking.” *Massachusetts v. EPA*, 415 F.3d 50, 58 (D.C. Cir. 2005). The dissent argued that CAA section 202(a)'s breadth provided the EPA sufficient authority to regulate GHGs, that more specific authorization was not required, and that the EPA's policy justifications were inadequate reasons to deny the petitions. *Id.* at 67–82 (Tatel, J., dissenting).

²⁴ Writing for four members of the Court, Chief Justice Roberts would have dismissed the petitions for review for lack of Article III standing. 549 U.S. at 535 (Roberts, C.J., joined by Scalia, Thomas, and Alito, J.J., dissenting). Writing for the same four members of the Court, Justice Scalia would have denied the petitions on the grounds that the Administrator reasonably exercised judgment in declining to regulate and that CAA section 302(g)'s definition of “air pollutant” does not clearly encompass CO₂ and other GHGs that naturally occur in the ambient air. 549 U.S. at 549 (Scalia, J., joined by Roberts, C.J., and Thomas and Alito, J.J., dissenting).

²⁵ In the 2008 ANPRM, the EPA noted that the most recently available IPCC analysis concluded that “[t]he anthropogenic combined heating effect (referred to as forcing) of [methane], N₂O, HFCs, PFCs and SF₆ is about 40% as large as the CO₂ cumulative heating effect since pre-industrial times.” 73 FR 44423.

approaches specific to particular GHGs. 73 FR 44438–63.

Following a change in administration, however, the EPA proposed in April 2009 and finalized in December 2009 a much different approach to analyzing GHG emissions from new motor vehicles and engines under CAA section 202(a). In the Endangerment Finding, the Administrator found that “the science [was] sufficiently certain” to compel an affirmative determination and interpreted *Massachusetts* as “allow[ing] for the consideration only of science.” 74 FR 66501. Relatedly, the Administrator did not consider any of the implementation challenges or options discussed in the 2008 ANPRM, asserting instead that CAA section 202(a) confers “procedural discretion” to issue standalone findings without considering a regulatory response because the statute “is silent on this issue.” *Id.* The Administrator also defined all six “well-mixed” GHGs collectively as the relevant “air pollutants” and “air pollution” for purposes of endangerment and causation or contribution, meaning the Endangerment Finding did not need to address the different characteristics or emission trends of any particular GHG. 74 FR 66516–21, 66536–57.

With respect to endangerment, the Administrator began by excluding adaptation—human responses that reduce potential adverse impacts—and mitigation—independent measures that reduce the causes of potential adverse impacts—from the analysis of global climate change concerns. 74 FR 66513. The Administrator acknowledged that “some level of autonomous adaptation will occur” and that “this separation means this approach may not reflect the actual conditions in the real world in the future, because adaptation and/or mitigation may occur and change the risks.” *Id.* Nevertheless, the Administrator reasoned that “it would be extremely hard to make a reasoned projection of human and societal adaptation and mitigation responses” because they are “largely political” or “individual personal judgments.” *Id.* Next, the Administrator relied on IPCC Assessment Report 4 (AR4) projections to find that global temperatures would likely increase between 1.8 to 4 degrees Celsius by 2100, with an uncertainty range of 1.1 to 6.4 degrees Celsius. 74 FR 66519. Operating within this analytical framework, the Administrator found that elevated global concentrations of GHGs from all foreign and domestic sources were responsible for increased global temperatures that were responsible in turn for indirect health risks driven by (1) more frequent

heat waves; (2) air quality effects, including increased formation of ozone, and (3) broader societal impacts related to increased frequency and severity of certain extreme weather events. 74 FR 66525.²⁶ The Administrator also found that GHG emissions could lead to welfare effects related to (1) food production and agriculture; (2) forestry; (3) water resources; (4) sea level rise; and (5) energy infrastructure and settlements, although the evidence was uncertain for several categories that may see near-term benefits. 74 FR 66531–35.²⁷ Importantly, the Administrator acknowledged that the understanding of public health and welfare in the Endangerment Finding was atypical, particularly with respect to considering indirect effects, but asserted the approach was necessary given the “unique” challenge presented by global climate change. 74 FR 66527.

With respect to contribution, the Administrator asserted broad authority to interpret the statutory standard because “[t]he language of CAA section 202(a) is silent regarding how the Administrator is to make her contribution analysis.” 74 FR 66544. Exercising that putative interpretive authority, the Administrator concluded that “it is reasonable to consider that lower percentages contribute than one may consider when looking at a local or regional problem involving fewer sources of emissions,” 74 FR 66545, because “all contributors must do their part” to avoid “a tragedy of the commons, whereby no country or source category would be accountable for contributing to the global problem of climate change,” 74 FR 66543. Next, the Administrator relied on data showing that existing motor vehicles and engines emitted four GHGs—CO₂, methane, and N₂O from engines, as well as HFCs from air conditioning units—that accounted for 4.3 percent of global GHG emissions at the time. On that basis, the Administrator found that GHG emissions from new motor vehicles and engines “contribute to the air pollution” consisting of the six “well-mixed” GHGs previously identified as a danger to public health or welfare. 74 FR 66537–39.

Crucially, the Endangerment Finding made clear that the EPA was acting

independently from any new congressional mandate. Rather, the Administrator interpreted CAA section 202(a) as setting out a standalone authority to issue findings that establish jurisdiction without considering implementation concerns and purported to rest the Endangerment Finding solely on a scientific judgment informed by the record as assembled by the Agency in 2009.

D. Implementation of the 2009 Endangerment Finding

In the years since issuing the Endangerment Finding, the EPA has promulgated GHG emission standards for various classes of new motor vehicles and engines in reliance on the Endangerment Finding and, as anticipated in the 2008 ANPRM, sought to expand the same analytical framework to regulatory provisions governing existing vehicles, stationary sources, aircraft, and oil and gas operations. For a full accounting of GHG emission standards adopted since 2009 under CAA section 202(a), see sections VI.B and VI.C of this preamble.

Following the Endangerment Finding, the EPA received multiple petitions for reconsideration from industry groups, States, and various organizations arguing that our approach in 2009 was legally and scientifically flawed and that external assessments by the IPCC, among others, had not adequately addressed recent criticisms of climate change science. The EPA denied these consolidated petitions in 2010 without notice and comment. Reiterating the scientific assertions from the technical support document (TSD) used in 2009, we emphasized that we had conducted an independent review of outside assessments in issuing the Endangerment Finding and asserted that the core conclusions of the Endangerment Finding remained valid notwithstanding the flaws raised by the petitioners. The EPA also issued a volume of response documents defending the methodologies and experts relied upon and concluded that no new information warranted reconsideration. 75 FR 49556.

In April 2022, the EPA denied, again without notice and comment, a new round of petitions for reconsideration and rulemaking asserting that the Endangerment Finding was legally and scientifically flawed and undermined by more recent scientific assessments. We acknowledged that several recent studies contradicted assessments by the USGCRP and IPCC but reaffirmed our earlier position that such assessment reports are entitled to greater weight

²⁶ The Administrator also noted that increased global temperatures could lead to changes in certain food- and water-borne pathogens and allergens (including increases in pollen resulting from increased plant growth at higher concentrations of CO₂) but did “not plac[e] primary weight on these factors.” 74 FR 66498, 66526.

²⁷ The Administrator relied on welfare impacts to water resources and sea level rise as providing “the clearest and strongest support for an endangerment finding.” 74 FR 66534.

than dissenting views.²⁸ We also considered criticisms of the EPA's Social Cost of Carbon (SCC) methodology out of scope because "the social cost of carbon played no role in the 2009 Endangerment Finding."²⁹ We further acknowledged that severing the endangerment and cause or contribute analysis from the development of subsequent regulations had impacted the EPA's approach to GHG emission standards, including because the Science Advisory Board (SAB) did not have the opportunity to review the Endangerment Finding as would otherwise have been required by the CAA.³⁰ Nevertheless, we reaffirmed our position that CAA section 202(a) grants "procedural discretion" to issue findings and emission standards separately and "decline[d] to exercise that discretion" differently.³¹

E. Reconsideration of the 2009 Endangerment Finding

Since the EPA published the 2009 Endangerment Finding, there have been developments in innovation, science, economics, and mitigation, as well as significant Supreme Court decisions that provide new guidance on how federal agencies should interpret the statutory provisions that Congress has tasked them with administering.³² Accordingly, the Administrator has now determined that the Endangerment Finding should be reconsidered to address legal and scientific developments that present reason to question the ongoing validity and reliability of its conclusions and to subject these important issues to public comment for the first time since 2009.

In initiating reconsideration, the Administrator explored all findings, support, questions, and ambiguities contained within the science relied upon by the Endangerment Finding. As acknowledged in the Endangerment Finding and recent reports, there are significant questions and ambiguities presented by both the observable realities of the past nearly two decades and the recent findings of the scientific community, including those summarized in the 2025 CWG Draft Report. There may also be as-yet-unidentified issues or discrepancies present in the underlying TSD and scientific justifications offered in the

Endangerment Finding. When confronted with science offering a diverse array of conclusions, methodologies, and explanations, the Administrator strove to inform his judgment to the most impartial extent possible. A more detailed discussion of the available climate science can be found in section IV.B.

III. Legal Framework for Proposed Action

A. Proposed Rescission of the Endangerment Finding

The statutory authority for this proposed action is the same as that relied upon in the prior actions at issue: CAA section 202(a)(1), which requires the Administrator to "prescribe" and "from time to time revise . . . standards" for certain air pollutants emitted by new motor vehicles and new motor vehicle engines "in accordance with the provisions of this section."³³ Unless provided otherwise by statute, an agency may revise or rescind prior actions so long as it acknowledges the change in position, provides a reasonable explanation for the new position, and considers legitimate reliance interests in the prior position.³⁴

The EPA proposes that nothing in the language of the statute prohibits or conditions our general authority to rescind prior actions. CAA section 202(a)(1) grants the Administrator discretion to "revise" standards prescribed "in accordance with the provisions of this section" and does not require retaining the same level of stringency when revising or rescinding existing standards. Moreover, the statute neither authorizes the Administrator to issue standalone findings that trigger a duty to regulate nor prohibits the Administrator from rescinding such findings. Rather, CAA section 202(a)(1) requires the Administrator to prescribe standards for emissions of any air pollutant by classes of new motor vehicles or engines when, in his judgment, emissions of such air pollutant by such classes of new motor vehicles or engines "cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare." Notably, the EPA has consistently assumed that it has the statutory authority to rescind the Endangerment Finding in reviewing the merits of petitions for reconsideration

since 2009 and did not state that we lack such reconsideration authority.³⁵

The EPA acknowledges that rescinding the Endangerment Finding as proposed would involve significant changes to the legal interpretations adopted in the Endangerment Finding and retained in subsequent actions. For example, if finalized, the interpretation of CAA section 202(a) proposed in this action would preclude the EPA from issuing standalone endangerment and contribution findings and would instead require the Agency to make findings for particular air pollutant emissions and classes of new motor vehicles and engines as an integral step in a rulemaking to prescribe standards for such emissions and classes, consistent with our decades-long practice prior to 2009 in regulating non-GHG air pollutants. Furthermore, if finalized, the interpretation of CAA section 202(a) proposed in this action would reverse the basis for the Endangerment Finding by concluding that global climate change concerns cannot satisfy the statutory standard for regulation under CAA section 202(a). For discussion of our proposed interpretation of CAA section 202(a) and related statutory provisions, see section IV.A of this preamble. For discussion of our alternative proposal to rescind the Endangerment Finding because the EPA exercised its authority under CAA section 202(a) unreasonably and because the Administrator no longer has confidence in the assumptions, methodology, and conclusions in the Endangerment Finding in light of the scientific record, see section IV.B of this preamble.

The EPA is also proposing additional statutory and policy rationales for repealing the GHG emission standards currently in effect for new motor vehicles and engines separate and apart from the proposed rescission of the Endangerment Finding. If finalized, these alternative rationales would change the novel position taken in rulemakings since 2009 to prescribe and revise GHG emission standards under CAA section 202(a).³⁶ For example, if finalized, our proposal to determine that there is no "requisite technology" for

³⁵ See, e.g., 2022 Denial at 7–10 (denying mandatory reconsideration under CAA section 307(d) and reviewing the petitions on the merits as rulemaking petitions under APA section 553(e)); 75 FR 49560–63 (denying mandatory reconsideration under CAA section 307(d) without asserting that the EPA lacked statutory authority to rescind or revise the Endangerment Finding).

³⁶ 75 FR 25324 (May 7, 2010); 76 FR 57106 (Sept. 15, 2011); 77 FR 62624 (Oct. 15, 2012); 81 FR 73478 (Oct. 25, 2016); 85 FR 24174 (Apr. 30, 2020); 86 FR 74434 (Dec. 30, 2021); 89 FR 27842 (Apr. 18, 2024); 89 FR 29440 (Apr. 22, 2024).

²⁸ 2022 Denial at 15–17.

²⁹ *Id.* at 30.

³⁰ *Id.* at 36 (noting that 42 U.S.C. 4365(c)(1) requires SAB consultation for a "standard" promulgated under CAA section 202(a) but asserting that requirement does not extend to "findings" issued under the same provision).

³¹ *Id.* at 39.

³² See Feb. 19, 2025 Memo at 1.

³³ 42 U.S.C. 7521(a)(1).

³⁴ See *Wages & White Lion*, 145 S. Ct. 898; *FCC v. Fox Television Stations, Inc.*, 556 U.S. 502 (2009); *Motor Vehicle Mfrs. Ass'n v. State Farm Mut. Auto. Ins. Co.*, 463 U.S. 29 (1983); *Clean Air Council v. Pruitt*, 862 F.3d 1, 8 (D.C. Cir. 2017) ("Agencies obviously have broad discretion to reconsider a regulation at any time.").

vehicle emission control capable of having a measurable impact on the dangers identified in the Endangerment Finding would preclude any GHG emission standards from going into effect. Furthermore, if finalized, our proposal to determine that the GHG emission standards harm public health and welfare on balance would make it unreasonable and contrary to the objectives of the statute to issue and retain such standards. See section V of this preamble for further discussion of these additional rationales and the Agency's prior positions.

The EPA acknowledges that repealing the GHG emission standards based on the proposed rescission of the Endangerment Finding would depart from our position in rulemakings since 2009 that prescribed and revised GHG emission standards for light- and medium-duty vehicles and heavy-duty vehicles and engines under CAA section 202(a). If finalized as proposed, the rescission would eliminate the statutory basis for those standards because we relied on the Endangerment Finding in each rulemaking to invoke our authority under CAA section 202(a) without making the required findings for GHGs emitted by the class or classes of new motor vehicles or engines at issue in each rulemaking. See section VI of this preamble for further discussion of each prior rulemaking and the regulatory changes that would be necessary to repeal all GHG emission standards currently in effect for new motor vehicles and engines on any of the bases proposed in this action.

As discussed throughout this preamble, the EPA is proposing these changes to comply with limits on our statutory authority under the best reading of CAA section 202(a), respond to legal and scientific developments that undermine the conclusions and assumptions of the Endangerment Finding, and realign Agency resources to prioritize core statutory responsibilities. Importantly, the Nation's policy response to global climate change concerns was a major issue in the 2024 presidential election, in which voters were presented with distinct legal and policy approaches and elected a candidate promising a change in policy. Under these circumstances, the election of a new Administration is an independent and sufficient basis for changing legal interpretation and policy within the boundaries set by statute.³⁷

³⁷ See *State Farm*, 463 U.S. at 59 (Rehnquist, J., concurring in part and dissenting in part); *PETA v. USDA*, 918 F.3d 151, 158 (D.C. Cir. 2019) ("new administrations are entitled to reevaluate and modify agency practices, even longstanding ones"); *Nat'l Ass'n of Home Builders v. EPA*, 682 F.3d

Democratic accountability is essential to the exercise of delegated authority by administrative agencies,³⁸ and retaining the Endangerment Finding without clear statutory authority would frustrate, not promote, constitutional values and the rule of law. If the EPA lacks authority to retain the Endangerment Finding under the best reading of CAA section 202(a), the statute controls regardless of policy preferences.

The EPA seeks comment on the nature and extent of any reliance interests that may have arisen from our assertion of regulatory authority over GHG emissions from new motor vehicles and engines and is committed to assessing any such interests, determining whether they are significant, and weighing such interests against competing rationales, as required by law.³⁹

Specifically, we seek comment on whether regulated parties have any significant reliance interests in our GHG emission standards for new motor vehicles and new motor vehicle engines. We are aware that manufacturers, importers, and sellers have already expended resources complying with GHG emission standards for MYs 2012 through 2026, and that consumer prices for vehicles in these MYs reflect the costs of such compliance. Because many compliance costs are incurred as part of research and development and during manufacturing, with the notable exception of the need to purchase compliance credits, this proposed action would have limited impacts on MYs 2012 to 2024, greater impacts for MYs 2024–2026, and would entirely relieve future regulatory obligations for MY 2027 and beyond. As discussed in sections VI.B and VI.C of this preamble, we are confident that the Agency has adequate regulatory tools to address transitional compliance concerns and note that this proposed action would not, if finalized, mandate any particular response by regulated parties. We are also aware that regulated parties may have reliance interests in national uniformity and CAA preemption with respect to emission standards for new motor vehicles and engines. As discussed in section VI.A of this preamble, CAA section 209(a) and other applicable sources of federal

1032, 1043 (D.C. Cir. 2012) ("the inauguration of a new President and the confirmation of a new EPA Administrator" went "a long way toward explaining why EPA" changed policy).

³⁸ See, e.g., *U.S. Telecom Ass'n v. FCC*, 855 F.3d 381 (D.C. Cir. 2017) (Brown, J., dissenting from denial of rehearing en banc); Elena Kagan, Presidential Administration, 114 Harv. L. Rev. 2245, 2252–53, 2332–34 (2001).

³⁹ See, e.g., *DHS v. Regents of Univ. of Cal.*, 591 U.S. 1, 33 (2020).

preemption would continue to apply, and we would retain our authority to regulate emissions, including emissions of the six "well-mixed" GHGs addressed in the Endangerment Finding, under circumstances that meet the standard for regulation under CAA section 202(a). We seek comment on each of these rationales, including on whether any reliance interests in national uniformity and preemption would support finalizing or not finalizing the proposed action, or adopting certain rationales and not finalizing other rationales. We further seek comment on the continued preemptive effect of the CAA in the event that the EPA finalizes the proposed rescission or any of the alternatives discussed herein (or in the event that the Agency determines that it lacks authority at the present time to regulate GHG emissions under one or more provisions of the CAA for any reason). As a general matter, we also seek comment on how we should repeal the Endangerment Finding and regulations if the decision is made to proceed with the proposed repeals, including under any of the options set out in this proposal or any additional grounds and means.

In addition, the EPA seeks comment on whether regulated parties and other stakeholders have significant reliance interests in GHG emission standards for new motor vehicles and engines. This proposed action would make only minor conforming adjustments to regulatory provisions for criteria pollutants and air toxics, thereby leaving most emission standards for new motor vehicles and engines in place. Nor would this proposed action impact separate economy and fuel-efficiency standards that have the effect of reducing GHG emissions per mile traveled from new motor vehicles and engines, including standards issued by NHTSA. As explained in section IV.A.1 of this preamble, we now believe that regulating GHG emissions based on global climate change concerns exceeds our statutory authority under CAA section 202(a) and, as such, propose that reliance interests alone would not justify retaining the GHG emission standards that we lacked authority to prescribe. As discussed in section IV.A.2 of this preamble, potential dangers from local or regional exposure to the six "well-mixed" GHGs covered by the Endangerment Finding are regulated separately under specific grants of statutory authority. And as discussed in section V of this preamble, we now believe that GHG emission standards for new motor vehicles and engines may harm public health and

welfare without having any measurable impact on the global climate change concerns identified in the Endangerment Finding. We seek comment on potential reliance interests in GHG emission standards for global climate change concerns under CAA section 202(a), including on whether such reliance justifies retaining standards in the absence of statutory authority and the extent to which potential dangers are addressed, or could be addressed, under more specific authorities.

The EPA recognizes that we have relied in part on the Endangerment Finding in issuing subsequent endangerment findings and GHG regulations under other CAA provisions, including for certain stationary sources and aircraft engines. The Supreme Court has since vacated several of these actions, including GHG regulations for existing sources in the fossil-fuel fired power plant source category under CAA section 111(d) and for permitted sources under CAA Title V.⁴⁰ For those actions that remain in effect, we have initiated or intend to initiate separate rulemakings that will address any overlapping issues.

Among other concerns with the Endangerment Finding, we believe that severing consideration of endangerment and causation or contribution from the appropriate regulatory response under CAA section 202(a) resulted in broad statements that did not account for the statutory language in CAA section 202(a)(1) on which the Endangerment Finding purported to rely. Congress used different authorizing language to address distinct issues for stationary sources regulated under CAA section 111 and aircraft engines regulated under CAA section 231. In reconsidering actions taken under these authorities, we intend to address prior findings and standards in light of the particular statutory language, policy concerns, and scientific information relevant to each context. In this proposed action, we seek comment on reliance interests in the Endangerment Finding and GHG emission standards issued under CAA section 202(a) and reserve the right to direct out of scope comments to the appropriate rulemaking docket for the applicable regulatory action.

B. Proposed Amendments to New Motor Vehicle and Engine Regulations

As noted above, CAA section 202(a)(1) directs the Administrator to prescribe “standards applicable to the emission of any air pollutant from any

class or classes of new motor vehicles or new motor vehicle engines, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.” This core directive has remained substantially the same since Congress enacted the Motor Vehicle Pollution Control Act of 1965.⁴¹ Thus, a necessary condition to regulating emissions from new motor vehicles and engines is a finding—an “endangerment finding”—that emissions of an air pollutant from a class or classes of new motor vehicles or engines cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare.

For the reasons discussed in section IV of this preamble, we are proposing to rescind the Endangerment Finding for GHG emissions from new motor vehicles and new motor vehicle engines and, on that basis, to repeal all existing GHG emission standards for passenger cars, light-duty trucks, motorcycles, buses, medium-duty vehicles, and heavy-duty vehicles and engines. The Endangerment Finding has served as the EPA’s basis for regulating GHG emissions from new motor vehicles and new motor vehicle engines since 2009. Absent findings of endangerment and causation or contribution, the EPA lacks statutory authority to prescribe standards for those emissions under CAA section 202(a)(1). We propose that when the EPA rescinds an endangerment finding for an air pollutant, it must cease prescribing and enforcing standards applicable to the emission of that pollutant from new motor vehicles or new motor vehicle engines and should rescind existing standards no longer authorized by statute.

For the reasons discussed in section V of this preamble, we are also proposing additional bases to repeal GHG emission standards even if the Endangerment Finding were to remain in place. We propose that regardless of whether GHG emissions trigger the standard for regulation in CAA section 202(a)(1), our authority to prescribe and enforce emission standards for GHGs is limited by the language of CAA section 202(a)(2) and must be exercised in a reasonable manner that furthers, rather than burdens, the health and welfare of all Americans.

Accordingly, the EPA is proposing to repeal all standards and associated test procedures adopted to limit the emission of GHGs under CAA section 202(a) for highway light-, medium-, and heavy-duty vehicles and engines. The

EPA notes that, for light-duty vehicles, the Energy Policy and Conservation Act of 1975 (EPCA) and the 2007 EISA authorize NHTSA to administer the CAFE program and fuel economy labeling program. These statutes also direct the EPA to determine compliance values for manufacturers subject to the CAFE program and the fuel economy labeling program. Importantly, these statutory obligations are distinct from the EPA’s authority under CAA section 202(a) and from the EPA’s decisions since 2009 to regulate GHG emissions under CAA section 202(a). As explained in section VI of this preamble, we are retaining and not proposing to reopen regulatory provisions related to our statutory roles in these NHTSA programs. Likewise, we are retaining and not proposing to reopen any criteria pollutant and air toxics standards for highway light-, medium-, and heavy-duty vehicles and engines under CAA section 202(a).

IV. Proposed Rescission of the Endangerment Finding

In this section, the EPA proposes to rescind the Endangerment Finding by concluding, based on multiple, independent alternative legal rationales, that the Agency’s unprecedented foray into regulating GHG emissions from new motor vehicles and engines is inconsistent with the best reading of CAA section 202(a). Under any proposed alternative, the EPA would lack authority to retain existing GHG emission standards for new motor vehicles and engines and proceed to repeal the relevant provisions of Title 40 of the CFR as proposed in section VI of this preamble.

Section IV.A of this preamble describes our primary proposal to rescind the Endangerment Finding by concluding that CAA section 202(a) does not authorize the EPA to prescribe standards for GHG emissions based on global climate change concerns or to issue standalone findings that do not apply the statutory standard for regulation as a cohesive whole. If finalized, this proposal would require rescinding the Endangerment Finding and resulting regulations because we lacked statutory authority to issue them in the first instance. We begin by proposing the best reading of CAA section 202(a) and related provisions, as informed by the Supreme Court’s decisions in *Loper Bright* and *UARG*. Next, we propose that the Nation’s response to global climate change concerns generally, and specifically whether that response should include regulating GHG emissions from new motor vehicles and engines, is an

⁴⁰ See *West Virginia*, 597 U.S. 697; *UARG*, 573 U.S. 302.

⁴¹ Public Law 89–272, 79 Stat. 992–93.

economically and politically significant issue that triggers the major questions doctrine under *UARG* and *West Virginia*, and that Congress did not clearly authorize the EPA to decide it by empowering the Administrator to “prescribe . . . standards” under CAA section 202(a). Throughout this section, we propose that the Endangerment Finding relied on various forms of *Chevron* deference⁴² to depart from the best reading of the statute and exceeded the EPA’s authority in several fundamental respects, any one of which would independently require rescission to conform to the best reading of the law.

Section IV.B of this preamble describes the EPA’s alternative proposal that regardless of whether CAA section 202(a) authorizes regulating GHG emissions based on global climate change concerns, we would rescind the Endangerment Finding by concluding that the Administrator analyzed endangerment and contribution in an unreasonable manner. We begin by recounting the interpretation of CAA section 202(a) adopted in the Endangerment Finding, which asserted “procedural discretion” to issue standalone findings without prescribing the standards required by such findings and to sever the analysis of endangerment from the analysis of contribution. Next, we propose that the Administrator exercised that discretion unreasonably by adopting an approach that papered over substantial uncertainties in the scientific record and failed to draw the required connection between GHG emissions from a class or classes of new motor vehicles and global climate change concerns. We further propose that developments since 2009 demonstrate the uncertainties acknowledged in the Endangerment Finding are more significant than previously believed, including because many of its predictive judgments involve ranges of assumptions that largely fail to satisfy the statutory standard for regulation and because the more pessimistic assumptions have not been borne out in empirical data and peer-reviewed studies through 2025. Finally, we propose that the Administrator would exercise any discretion conferred by CAA section 202(a) differently to ensure a legally and scientifically sound approach and that, under that approach, the Endangerment

Finding and resulting GHG emission standards must be rescinded.

We seek comment on every aspect of the primary and alternative proposal, including the key issues on which we specifically request comment as set out in section VII of this preamble.

A. Primary Rationale for Proposed Rescission

The Endangerment Finding announced an interpretation of CAA section 202(a) that permitted the EPA to prescribe standards in response to global climate change concerns rather than local or regional exposures, granted “procedural discretion” to issue standalone findings without considering regulatory response, and severed the finding of endangerment from the finding of contribution to that endangerment. At the time, we assumed that statutory silence granted discretion to construe the scope of our authority and asserted or implied that the Supreme Court’s decision in *Massachusetts* required us to read the statute as authorizing the regulation of GHG emissions in response to global climate change concerns.

In important respects, the Endangerment Finding and the Supreme Court’s decision in *Massachusetts* straddled a transitional period regarding the standards for statutory interpretation and understandings of agency authority. The breadth of agency discretion, and the question whether Congress reserves major policy questions for itself, were sharply disputed. Judicial decisions in the intervening fifteen years have significantly clarified the law in both respects. In *Loper Bright*, the Supreme Court expressly overturned the doctrine of deference to agency statutory interpretation, ruling that statutes “have a single, best meaning” that is informed, but not dictated, by Executive Branch practice. 603 U.S. at 400–01. And in *West Virginia*, the Supreme Court built upon its decisions in *UARG* and *Brown & Williamson*, among others, by confirming that an agency must have more than “a colorable textual basis” to claim authority to decide major questions of policy that Congress would generally reserve for itself in the first instance. 597 U.S. at 723.

In this subsection, we propose that the best reading of CAA section 202(a), as informed by *Loper Bright* and principles of statutory interpretation, does not authorize the EPA to assert jurisdiction over GHG emissions based on global climate change concerns in a standalone endangerment finding. Regardless whether GHGs are properly considered “agents of air pollution” under the general, Act-wide definition

of “air pollutant” at CAA section 302(g), the EPA cannot regulate under CAA section 202(a) unless the emissions of the air pollutant by a class or classes of new motor vehicles “cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.” Because the text, structure, and history of CAA section 202(a) and related provisions demonstrate that this language targets air pollution that threatens public health or welfare through local or regional exposure, “air pollution” defined as six “well-mixed” GHGs raising global climate change concerns that adversely impact a subset of regions globally cannot satisfy this standard. We further propose that this reading is independently confirmed and strengthened by the major questions doctrine. Specifically, we propose that the major questions doctrine applies and precludes the EPA from asserting authority to regulate in response to global climate change concerns under CAA section 202(a). At a minimum, Congress did not clearly authorize the EPA to decide the Nation’s response to global climate change concerns by empowering the Agency to “prescribe . . . standards” for certain air pollutants emitted by new motor vehicles and engines. On these bases, and on account of the additional procedural and analytical errors set out below, we propose that the Endangerment Finding exceeded the EPA’s authority and must be rescinded.

1. Best Reading of CAA Section 202(a)

Congress originally enacted the language of CAA section 202(a) in the Motor Vehicle Pollution Control Act of 1965 and retained it, with minor revisions, in the 1970 CAA and all subsequent statutory amendments. The key language in CAA section 202(a)(1) provides:

The Administrator shall by regulation prescribe (and from time to time revise) in accordance with the provisions of this section, standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles or new motor vehicle engines, which in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.⁴³

Since 1977, CAA section 302(g) has defined the term “air pollutant” throughout the statute as “any air pollution agent or combination of such agents . . . which is emitted into or otherwise enters the ambient air.”⁴⁴

⁴³ 42 U.S.C. 7521(a)(1).

⁴⁴ 42 U.S.C. 7602(g). Notably, the statute does not separately define “air pollution.”

⁴² *Chevron U.S.A., Inc. v. NRDC, Inc.*, 467 U.S. 837 (1984), overruled by *Loper Bright*, 603 U.S. 369; see 74 FR 66501, 66502, 66544 (asserting discretion based on statutory ambiguity, including that created by silence); 74 FR 66528, 66542, 66543 (asserting discretion based on statutory ambiguity).

CAA section 302(h) also provides that any reference to “effects on welfare includes, but is not limited to, effects on” the environment, property, transportation hazards, and “on economic values and on personal comfort and well-being.”⁴⁵

The EPA proposes that this statutory language is best read as authorizing the Agency to identify and regulate, as an integral part of a rulemaking prescribing emissions standards, air pollutants that cause or contribute to air pollution that itself endangers public health and welfare through local or regional exposures. This proposed interpretation is consistent with the text and structure of the statute, our decades-long implementation of the statute prior to 2009, and background principles of statutory interpretation, including default rules for proximate cause. This proposed interpretation is also consistent with the Supreme Court’s decision in *Massachusetts*, which addressed distinct issues and must, as a matter of *stare decisis*, be read in harmony with the Supreme Court’s subsequent decisions bearing on the EPA’s authority and statutory interpretation in *UARG*, *West Virginia*, and *Loper Bright*.⁴⁶

Dangerous Air Pollution. The EPA proposes that CAA section 202(a) is best read as authorizing the Agency to regulate air pollutant emissions that cause or contribute to air pollution that endangers public health or welfare through local or regional exposure. For the purposes of this proposed action, we use the phrase local or regional exposure to distinguish air pollution that impacts public health and welfare by its presence in the ambient air from “air pollution” consisting of six “well-mixed” GHGs that, as conceptualized in the Endangerment Finding, impacts public health and welfare only indirectly and not by its mere presence in the ambient air. As discussed below, this proposal would effectively return the EPA to its interpretation of CAA section 202(a) prior to 2009.

We propose that the terms “air pollutant” and “air pollution” as used in CAA section 202(a)(1) should be construed in accordance with the specific air pollutants identified for other purposes in the remainder of CAA section 202. Each of these listed air

pollutants share the common quality of causing or contributing to air pollution that adversely impacts public health or welfare through local or regional exposure to the air pollution itself. CAA section 202 specifically addresses hydrocarbons (HCs), carbon monoxide (CO), oxides of nitrogen (NO_x), and particulate matter (PM), all of which harm health and the environment through exposure (e.g., inhalation and dermal contact) or by causing or contributing to air pollution that harms health and the environment through exposure (e.g., smog and acid rain).⁴⁷ That pattern holds for the criteria pollutants identified in the CAA—CO, lead, ground-level ozone (O₃), nitrogen dioxide (NO₂), PM, and sulfur dioxide (SO₂)—as well as the initial list of hazardous air pollutants in CAA section 112(b)(1).⁴⁸ We find it significant that in subjecting a number of air pollutants emitted by new motor vehicles and engines to regulation under CAA section 202, Congress did not include substances that are potentially indirectly harmful to public health or welfare based on elevated global concentrations in the upper atmosphere. That conspicuous omission supports the conclusion that the air pollutants subject to regulation under CAA section 202(a) are those that cause or contribute to air pollution which itself endangers public health or welfare through local or regional exposure.⁴⁹

Put another way, we propose that the air pollutants identified in CAA section 202 and throughout relevant provisions of the CAA are those that cause or contribute to air pollution for which the air pollution *itself*, through local or regional exposure to humans and the environment, endangers public health or welfare.⁵⁰ For certain regulated air pollutants, the air pollutants are themselves the dangerous air pollution, *i.e.*, the air pollutants are the air

pollution with adverse health and welfare impacts. An example is CO, which can be harmful, and even fatal, to humans at sufficient localized concentrations.⁵¹ For other regulated air pollutants, the air pollutants contribute to dangerous air pollution by interacting with other airborne chemicals or environmental factors such as sunlight to create the dangerous air pollution, *i.e.*, the air pollutants are ingredients that create the dangerous air pollution in combination. An example is acid rain, in which air pollutants such as SO₂ interact locally and regionally with additional airborne chemicals to form acidic precipitation.⁵²

The definition of “air pollutant” in CAA section 302(g) and the meaning of the undefined terms pollutant, pollution, and air pollution support this reading. As a matter of ordinary language, a pollutant is “[a] poisonous or noxious substance that contaminates the environment,” and pollution is “[t]he harmful addition of a substance or thing into an environment.”⁵³ Definitions of air pollution similarly emphasize the emission of “[c]ontaminants into the atmosphere.”⁵⁴ The central concept is the addition of a contaminant, something, that “make[s] impure or unclean by contact or mixture.”⁵⁵ CAA section 302(g) is consistent with these definitions, adding only that an “air pollutant” is any “air pollution agent or combination of such agents” that “is emitted into or otherwise enters the ambient air.”⁵⁶ Read together with CAA section 202(a)—as the Supreme Court held we must in *UARG*—the underlying concept of dangerousness and contamination reinforces the conclusion that air pollution which endangers public health or welfare is air pollution (caused or contributed to by air pollutants) that itself endangers public health or welfare through local or regional exposures.

The “air pollution” addressed in the Endangerment Finding is different in kind. In that decision, the Administrator defined the relevant “air pollutants” as six “well-mixed GHGs” and the relevant “air pollution” as “the combined mix of” these GHGs “which together,

⁴⁷ See, e.g., 42 U.S.C. 7521(a)(3)(A)(i), (b), (g), (h), (j), (k).

⁴⁸ 42 U.S.C. 7412(b)(1).

⁴⁹ As discussed in section IV.A.2 of this preamble, the only references to GHGs in the CAA are in non-regulatory contexts in which Congress authorized funding for various forms of research and grant programs. The choice to limit such references to non-regulatory solutions further supports the conclusion that the CAA section 202(a) regulatory authority for responding to endangerment does not encompass GHG emissions on the basis of global climate change concerns.

⁵⁰ For example, unlike other regulated air pollutants, “CO₂ is odorless, does not affect visibility and has no toxicological effects at ambient levels.” Additionally, the Permissible Exposure Limit established by the U.S. Occupational Safety and Health Administration or which diminished performance on cognitive tasks are “far larger than any plausible ambient outdoor value through the end of the 22nd century.” Add 2025 CWG Draft Report at 2.

⁵¹ U.S. Environmental Protection Agency. (Last updated Apr. 11, 2025). Carbon Monoxide’s Impact on Indoor Air Quality: <https://www.epa.gov/indoor-air-quality-iaq/carbon-monoxides-impact-indoor-air-quality>.

⁵² U.S. Environmental Protection Agency. (Last updated Mar. 4, 2025). What is Acid Rain?: <https://www.epa.gov/acidrain/what-acid-rain>.

⁵³ Black’s Law Dictionary 1403 (11th ed. 2019).

⁵⁴ *Id.*

⁵⁵ Am. Heritage Dictionary (5th ed. 2022).

⁵⁶ 42 U.S.C. 7602(g).

⁴⁵ 42 U.S.C. 7602(h).

⁴⁶ See *Hohn v. United States*, 524 U.S. 236, 252–53 (1998) (Supreme Court decisions “remain binding precedent until [the Supreme Court] see[s] fit to reconsider them, regardless of whether subsequent cases have raised doubts about their continuing vitality.”); *Rodriguez de Quijas v. Shearson/Am. Exp., Inc.*, 490 U.S. 477, 484 (1989) (similar).

constitute the root cause of human-induced climate change and the resulting impacts on public health and welfare.” 74 FR 66516. In contrast to the air pollution addressed expressly in CAA section 202 and elsewhere in the statute, GHGs do not endanger public health or welfare through local or regional exposure. Rather, the Endangerment Finding asserted that GHG “air pollution” would *lead to* increases in global temperature and change to ocean pH that, in turn, would *lead to* environmental phenomena, in combination with an open-ended universe of additional factors, which would potentially have adverse public health and welfare impacts of varying severity in certain regions. Regulating GHG emissions based on global climate change concerns requires reading an additional instance of “cause, or contribute” into the statute, such that CAA section 202(a) encompasses the ‘emission of air pollutants that cause, or contribute to, dangerous air pollution that causes, or contributes to, endangerment of public health or welfare.’

This proposed interpretation is also supported by the best reading of the terms “cause” and “contribute.” In enacting and amending CAA section 202(a), Congress legislated against background legal principles, including principles of causation and proximate cause.⁵⁷ These “default rules” are “presumed to have [been] incorporated, absent an indication to the contrary in the statute itself,”⁵⁸ and nothing in the text of CAA section 202(a) indicates that Congress intended to depart from ordinary legal meaning. As a general matter, there is a point at which harm no longer has a sufficiently close connection to the relevant conduct to reasonably draw a causal link. We propose that emissions from new motor vehicles and new motor vehicle engines in the United States do not have a sufficiently close connection to the adverse impacts identified in the Endangerment Finding to fit within the legal meaning of “cause” or “contribute.” The Endangerment Finding largely avoided addressing this problem by severing the question whether GHG emissions from new motor vehicle engines contribute to GHG concentrations in the atmosphere from the question whether GHG concentrations in the atmosphere

endanger public health and welfare. As discussed in further detail in section IV.A.1 of this preamble, we propose that there is no basis in the statute for severing the inquiry in that way. Nevertheless, even with respect to endangerment and contribution in isolation, we propose that global climate change concerns involve analyzing causal relationships that are too uncertain, too remote, and too confounded by intervening and confounding factors to fit within the terms “cause” and “contribute” as used in CAA section 202(a). This understanding follows from the position discussed above that CAA section 202(a) and the statute more generally were designed to regulate air pollution with harmful impacts from local and regional exposure that are analyzable by ordinary causation standards.

In proposing this interpretation, we note that a limiting construction is necessary to avoid absurd results and potential conflict with the nondelegation doctrine. Because Congress cannot delegate legislative powers to the Executive Branch, statutes granting an agency regulatory authority must provide an intelligible principle to guide its exercise.⁵⁹ Our authority under CAA section 202(a) to “prescribe . . . standards” for air pollutant emissions by a class or classes of new motor vehicles and engines is limited by the requirement that the Administrator find such air pollutants cause or contribute to air pollution that may reasonably be anticipated to endanger public health and welfare. We propose that the best reading of the statute circumscribes this authority to air pollution that itself causes or contributes to endangerment of public health or welfare. Under the interpretation adopted in the Endangerment Finding, however, our authority under CAA section 202(a) would have no readily discernible limiting principle, particularly in combination with the authority asserted to sever the analysis of endangerment and causation or contribution. Following the logic of the Endangerment Finding, any “air pollutant” emitted at more than *de minimis* volumes would trigger our authority, and the statutory obligation, to prescribe standards so long as the emission contributes to “air pollution” that, in turn, potentially contributes to phenomena with predicted adverse impacts on public health and welfare broadly defined. As discussed further below, under this logic, the release of water vapor (H₂O) would meet the

standard for regulation because water can be said to result in significant harms and because motor vehicles and engines can be said to “contribute” to that harm by emitting non-*de minimis* quantities of water vapor into the upper atmosphere. The EPA would have the authority, and statutory duty, to prescribe standards for water vapor emissions because water vapor is a recognized GHG emitted by motor vehicles and engines as well as the vast majority of other mobile and stationary sources. Because that reading effectively converts CAA section 202(a)(1) into a roaming license to “prescribe . . . standards,” we believe the reading proposed herein is more faithful to the governing principles of statutory interpretation.

We further emphasize that this proposed interpretation would effectively return the EPA to its longstanding practice prior to 2009 of applying CAA section 202(a) and related statutory endangerment provisions to air pollution that adversely impacts public health and welfare through local or regional exposure. As noted above, we historically utilized this authority to prescribe standards for pollutants identified in the CAA itself, including NO_x, PM, HC, and CO. The distinction between air pollution that harms public health and welfare through local and regional exposure and global “air pollution” consisting of GHG concentrations without any such direct impacts has also played a role in our evaluation of waiver requests under CAA section 209.⁶⁰ Even in the Endangerment Finding, the Administrator recognized that we had previously applied CAA section 202(a) to “a *more typical* local or regional air pollution problem.” 74 FR 66538 (emphasis added). We propose that in adopting a novel analytical approach in the Endangerment Finding, the EPA failed adequately to address its prior practice and improperly relied on the Supreme Court’s decision in *Massachusetts* for the proposition that CAA section 202(a) authorizes emission standards in response to air pollution raising global climate change concerns. As discussed below, *Massachusetts* did not construe the scope of the EPA’s authority to regulate under CAA section

⁵⁷ See, e.g., *Bank of Am. Corp. v. City of Miami*, 581 U.S. 189, 201 (2017); *Lexmark Int’l, Inc. v. Static Control Components, Inc.*, 572 U.S. 118, 132 (2014); *Univ. of Tex. Sw. Med. Ctr. v. Nassar*, 570 U.S. 338, 347 (2013); *City of Oakland v. Wells Fargo & Co.*, 14 F.4th 1030 (9th Cir. 2021) (en banc).

⁵⁸ *Nassar*, 570 U.S. at 347.

⁵⁹ See, e.g., *Gundy v. United States*, 588 U.S. 128 (2019).

⁶⁰ See, e.g., “California State Motor Vehicle Pollution Control Standards; Notice of Decision Denying a Waiver of Clean Air Act Preemption for California’s 2009 and Subsequent Model Year Greenhouse Gas Emission Standards for New Motor Vehicles,” 73 FR 12156, 12161 (Mar. 6, 2008) (denying California’s waiver request for GHG emission standards on the ground that “the different, and global, nature of the pollution at issue” requires a different conceptual approach).

202(a), and the Court has since made clear in *UARG* and *West Virginia* that our authority to regulate air pollutants that fit within the Act-wide definition turns on the particular statutory provision that confers authority to regulate.

In *Massachusetts*, the Supreme Court rejected the argument that GHGs are not “air pollutants” under the Act-wide definition, reasoning that CAA section 302(g)’s use of the word “any” in connection with “air pollutant agent or combination of such agents, including any physical [or] chemical . . . substance” was sufficiently broad to encapsulate the combination of GHGs at issue. 549 U.S. at 530. On this basis, the Court stated that the EPA “has the statutory authority to regulate the emission of such gases from new motor vehicles.” *Id.* at 532. The Court did not, however, decide whether including GHGs within the definition of “air pollutant” meant that we must find that GHGs meet the statutory standard for regulation under CAA section 202(a) because they cause or contribute to air pollution which endangers the public health or welfare. Rather the Court concluded its opinion by clarifying that it “need not and do[es] not reach the question whether on remand EPA must make an endangerment finding.” *Id.* at 534.

Consistent with *Massachusetts*, we propose to interpret the CAA as setting out a broad, threshold definition of “air pollutant” on an Act-wide basis that must be interpreted in the context of each applicable, particular provision granting regulatory authority in order to determine whether that provision authorizes the EPA to regulate an air pollutant under that particular authority. For purposes of CAA section 202(a), that means that even if GHGs are “air pollutant[s]” as defined on an Act-wide basis, they must meet the statutory standard for regulating emissions from new motor vehicles and engines before we may invoke our regulatory authority. Put simply, regardless whether GHGs are “air pollutants” as defined in CAA section 302(g), they must still satisfy the same standard as any other “air pollutant” by causing or contributing to air pollution which may reasonably be anticipated to endanger public health or welfare.

This understanding is confirmed by *UARG*, in which the Supreme Court distinguished between “the Act-wide definition” of air pollutant and the application of that definition to the Act’s regulatory provisions. 573 U.S. at 320. The Court specifically addressed the holding in *Massachusetts*, adopting the argument that “while *Massachusetts*

rejected EPA’s categorical contention that [GHGs] could not be air pollutants for any purposes of the Act, it did not embrace EPA’s [then] current, equally categorical position that [GHGs] must be air pollutants for all purposes regardless of the statutory context.” *Id.* (cleaned up).

In sum, we propose that CAA section 202(a) does not provide authority to regulate GHGs based on global climate change concerns because that provision authorizes regulating only air pollutants that “cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.” The EPA must “ground its reasons for action or inaction in the statute,” *Massachusetts*, 549 U.S. at 535, and “possess[es] only the authority that Congress has provided,” *NFIB v. DOL*, 595 U.S. 109, 117 (2022). In proposing this interpretation, we note that our actions must be consistent with “the single, best meaning” of the statute and cannot expand our authority in response to pressing concerns based on statutory silence or ambiguity. *Loper Bright*, 603 U.S. at 400, 411. We seek comment on this proposed interpretation, including the rationales articulated above and any further rationales that commenters believe support, or detract from, this interpretation.

Findings and Standards. The EPA further proposes that CAA section 202(a) requires issuing emission standards together with the findings necessary to invoke our regulatory authority, rather than severing the regulatory action into separate endangerment and standards-setting proceedings. The statute begins by providing that the Administrator “shall prescribe . . . standards applicable to the emission of any air pollutant from any class or classes of new motor vehicles or new motor vehicle engines,” and follows this requirement by describing the scope of the duty to regulate air pollutant emissions “which, in his judgment cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.” We propose that the best reading of the statute requires the Administrator, when prescribing any emission standard for new motor vehicles or engines, to find that the air pollutant or air pollutants emitted by the class or classes of new motor vehicles or engines subject to the standard cause or contribute to air pollution that may reasonably be anticipated to endanger public health or welfare.

The Endangerment Finding severed this statutory language by finding endangerment and contribution in the

abstract for all potential CAA section 202(a) sources with respect to GHGs. In so doing, the Administrator vastly increased the Agency’s authority by removing the restrictions Congress placed on the issuance of emission standards. As a result of this new conception of authority, the EPA may issue a single endangerment finding in the abstract with respect to emissions from all sources potentially subject to CAA section 202(a) (and their existing-source counterparts) without addressing the danger posed by any particular source category or the causal role of that particular source category in any identified danger. The EPA has since relied on the Endangerment Finding to prescribe emission standards for various classes of new motor vehicles and engines, as well as a variety of other sources under distinct statutory authorities, without making the requisite findings or assessment of factors necessary to regulate the sources in question.⁶¹ We propose that Congress enacted CAA section 202(a) as an integrated regulatory provision for a reason, and that giving effect to the language of the statute requires the issuance of emission standards only when the Administrator has made an integrated finding of both endangerment and cause or contribution. Put another way, we propose that it is impermissible for the Administrator to make an endangerment finding without prescribing the emission standards required in response to such a finding, and conversely, that it is impermissible to prescribe emission standards without making the source- and air-pollutant specific findings required by the statute.

This proposed interpretation is consistent with the EPA’s implementation of CAA section 202(a) and similar provisions of the CAA prior to 2009. In the Endangerment Finding, the Administrator acknowledged that “typically endangerment and cause or contribute findings have been proposed concurrently with proposed standards under various sections of the CAA, including CAA section 201(a).” 74 FR 66501. We propose that our historical practice under CAA section 202(a) reflects the better reading of the statute and is entitled to greater weight. As the Supreme Court recently explained, such weight is “especially warranted when an Executive Branch interpretation was issued roughly contemporaneously with enactment of the statute and remained consistent over time.” *Loper Bright*, 603 U.S. at 386.

⁶¹ See sections II.C, VI.B, and VI.C of this preamble for a summary of the EPA’s rulemaking activities in response to the Endangerment Finding.

In departing from the EPA's historical practice in the Endangerment Finding, the Administrator reasoned that "[t]he text of CAA section 202(a) is silent on this issue" and "invoked the procedural discretion that is provided by CAA section 202(a)'s lack of specific direction." 74 FR 66501. We propose that CAA section 202(a) is not silent on the issue because the statute sets out an integrated process that requires the EPA to prescribe standards when the Administrator finds certain conditions are met. When Congress intends a multi-step inquiry in the environmental context, it typically says so expressly. In the National Ambient Air Quality Standards (NAAQS) program, for example, the CAA separates our authority to establish and revise the NAAQS under CAA section 108 and 109 from our duties to implement the NAAQS by reviewing State Implementation Plans (SIPs) or promulgating Federal Implementation Plans (FIPs) under CAA section 110 and related statutory provisions.⁶² A particularly relevant analogy is Clean Water Act section 303(c)(4), which pairs the Administrator's authority to "determin[e] that a revised or new [water quality standard] is necessary to meet the requirements of this chapter" with the requirement that the Administrator "shall promptly prepare and publish proposed regulations" after making such a determination and "promulgate any revised or new standard . . . not later than ninety days after he publishes such proposed standards."⁶³ We further propose that even if CAA section 202(a) were ambiguous or silent in this respect, the Supreme Court recently held in no uncertain terms that "statutory ambiguity . . . is not a reliable indicator of actual delegation of discretionary authority to agencies." *Loper Bright*, 603 U.S. at 411.

Severing the EPA's standards-setting authority from the findings that trigger a duty to exercise that authority shaped the analysis in the Endangerment Finding in a manner that we propose ran counter to the statute. Recall that the Endangerment Finding first projected adverse public health and welfare impacts of global climate change and attributed those adverse impacts to all manmade sources of GHG emission around the world and then, separately,

used data from existing CAA section 202(a) sources in the United States to find that new motor vehicles and engines in the United States contributed to global GHG air pollution. The Administrator treated adaptation (adjustments to the effect of climate change that lessen impacts) and mitigation (reductions in emissions and global GHG concentrations unrelated to CAA section 202(a) regulation) as outside the scope. 74 FR 66512. Moreover, the Administrator declined to consider cost, asserting that the Endangerment Finding imposed no regulatory requirements as a standalone action and relying on the Supreme Court's decision in *Whitman v. American Trucking Association*, 531 U.S. 457 (2001), that the EPA cannot consider cost in setting and revising the NAAQS under CAA section 109. 74 FR 66515. Nor did the Administrator consider potential beneficial impacts from climate change with respect to whether and which standards would be appropriate. *See* 74 FR 66524 (purporting to compare "risks and benefits" only with respect to endangerment).

Severance also shaped all subsequent standards prescribed and revised in reliance on the Endangerment Finding in a manner we propose to conclude was unlawful. The EPA asserted in subsequent rulemakings that there was no need to make particularized findings for the relevant source category because the Endangerment Finding identified public health and welfare dangers and contribution for all CAA section 202(a) source categories. Nor did we consider the impacts of adaptation or mitigation or consider when prescribing standards whether, in light of more recent empirical data, the Endangerment Finding's analysis of endangerment and contribution remained accurate with respect to the source category at issue. As a result, the decision to sever meant that the EPA has never meaningfully considered or invited public comment on the cost, effectiveness, and continued propriety of its GHG regulatory program.

We propose that these considerations should have been taken into account when the 2009 Endangerment Finding intentionally triggered a duty to regulate by invoking our CAA section 202(a) authority. CAA section 202(a)(2) expressly provides that "[a]ny regulation prescribed under paragraph (1) of this subsection . . . shall" provide adequate time for "the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such

period."⁶⁴ CAA section 202(a)(1) authorizes the Administrator to "by regulation prescribe" standards "in accordance with the provisions of this section" and does not separately authorize standalone findings, meaning any action taken "under paragraph (1) of this subsection" is subject to the considerations in paragraph (2). That statutory language aside, the Supreme Court explained in *Michigan* that "agency action is lawful only if it rests 'on a consideration of the relevant factors,'" 576 U.S. at 750 (quoting *State Farm*, 463 U.S. at 43), including "at least some attention to cost," *id.* at 752. We propose that the Administrator erred in analogizing to the NAAQS program and the Supreme Court's decision in *Whitman* to avoid considering costs in the Endangerment Finding. Unlike CAA section 202(a), the language in CAA section 109(b) makes no reference to cost or implementation and focuses solely on safety and an adequate margin to protect public health. Nor does CAA section 109(b) include the lead time and technical feasibility concepts embedded in CAA section 202(a). And whereas CAA section 202(a) sets out an integrated authority to prescribe emission standards when the provision's triggering condition is satisfied, CAA section 109(b) uses mandatory language requiring the EPA to establish certain standards, the content and implementation of which are specified in various provisions throughout Title I of the Act. We further propose that the Supreme Court's decision in *Massachusetts* did not address the question whether the EPA could issue standalone findings or bar the Administrator from taking cost and implementation concerns into account when exercising CAA section 202(a) authority. Rather, *Massachusetts* must be read together with *Michigan*, and the language of CAA section 202(a)(1) must be read in context to "produc[e] a substantive effect that is compatible with the rest of the law." *UARG*, 573 U.S. at 321 (quoting *United Sav. Ass'n of Tex. v. Timbers of Inwood Forest Assocs.*, 484 U.S. 365, 371 (1988)).

Endangerment and Cause or Contribute. The EPA also proposes that CAA section 202(a) requires the Agency to evaluate whether source emissions cause or contribution to air pollution and whether that air pollution poses endangerment in a single causal chain, rather than considering these issues in isolation by severing the inquiries. The relevant inquiry is whether "the emission of any air pollutant from any class or classes of new motor vehicles or

⁶² See 42 U.S.C. 7408, 7409, 7410.

⁶³ 33 U.S.C. 1313(c)(4), (c)(4)(B). Various provisions of the Safe Drinking Water Act (SDWA) and Toxic Substances Control Act (TSCA) similarly articulate multi-step processes for determining risk and addressing risk through regulation using language that Congress did not include in CAA section 202.

⁶⁴ 42 U.S.C. 7521(a)(2).

new motor vehicle engines,” in the judgment of the Administrator, “cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.” As explained in this section, the emission must cause or contribute to the danger posed by the air pollution to a sufficient extent to satisfy the standard for regulation.

In the Endangerment Finding, the Administrator made two distinct findings based on two distinct sets of assumptions. In the first, the Administrator found that the “air pollution,” defined as the combined elevated global concentrations in the upper atmosphere of six “well-mixed GHGs,” CO₂, methane, NO_x, HFCs, PFCs, and SF₆, endangered public health or welfare by playing a causal role in global temperature increases and ocean pH changes, which, in turn, were then asserted to play a causal role in environmental phenomena with adverse impacts on public health and welfare. 74 FR 66516. In the second, the Administrator found that the “air pollutant” (defined as the combination of same six “well-mixed GHGs”) emitted by new motor vehicles and engines contributed to the “air pollution.” 74 FR 66536. Nowhere in the Endangerment Finding did the Administrator consider the extent to which emissions from CAA section 202(a) sources have a more than *de minimis* effect on the danger identified with respect to elevated concentrations of GHGs in the upper atmosphere—let alone whether emissions from any particular class or classes of sources that EPA intended to regulate had such an effect.

Upon review, we no longer believe that the approach taken in the Endangerment Finding was consistent with the language of CAA section 202(a) and the structure of the CAA, which requires making distinct findings for regulating distinct types of emission sources and authorizes different regulatory tools when such standards are met. For example, CAA section 111(b)(1)(A) authorizes the EPA to regulate emissions from listed categories of stationary sources if the Administrator determines those sources emit air pollutants that “significantly contribute” to dangerous air pollution.⁶⁵ When that standard is met, CAA section 111(b)(1)(B) requires the EPA to regulate such emissions from such sources by setting standards of performance that, among other things, reflect the best system of emission reduction that has been adequately demonstrated in

practice.⁶⁶ The CAA similarly sets out distinct standards for regulating and distinct modes of regulation for additional major source categories, including vehicles in use, aircraft engines, and separately addresses when and how to respond to international emissions that impact the United States. The Endangerment Finding effectively attributed the total GHG emissions coming from all of these various distinct sources within the United States, as well as from all international sources, to the mobile sources regulated under CAA section 202(a) without having made the requisite determinations for any of those sources and without considering the different regulatory tools Congress authorizes for those sources as compared to CAA section 202(a) sources. The Administrator defined the relevant “air pollution” as the combination of six “well-mixed GHGs” but found that CAA section 202(a) sources emitted only four of them: CO₂, methane, NO_x, and HFCs. 74 FR 66538. As a result, the “air pollution” identified as endangering public health or welfare included PFCs and SF₆, and the “air pollution” used to conclude that CAA section 202(a) sources satisfy the regulatory standard did not. Contrary to the EPA’s conclusion at the time, 74 FR 66541, that difference is material, as PFCs and SF₆ are asserted to have many times the global warming potential of CO₂.⁶⁷ Severing the endangerment and cause-or-contribute analysis allowed the Agency to compare apples and oranges in a manner the statute does not authorize.

The Endangerment Finding also did not limit its analysis of contribution to “new motor vehicles or new motor vehicle engines” in the United States, which are the only sources covered by the EPA’s CAA section 202(a) authority.⁶⁸ Because the Administrator considered all sources in analyzing the danger posed by elevated concentrations of GHGs in the upper atmosphere, the endangerment analysis necessarily included emissions from foreign and domestic vehicles that had been in use for years or decades and were not “new.” Even when analyzing contribution, the Administrator used emission estimates from “the entire fleet

of motor vehicles in the United States for a certain calendar year” rather than projecting emissions from new motor vehicles and engines over time. 74 FR 66543. That decision increased the absolute contribution figure by orders of magnitude, including because newer vehicles and engines tend to be more efficient and emit less.⁶⁹ Difficulties in disaggregating emission data from emission sources, however reasonable, do not license us to read the term “new” out of the statutory text.

We are also concerned that severing the endangerment and cause or contribution findings leads to untenable results and lacks any limiting principle. To illustrate the problem, the same logic would allow the EPA to issue emission standards for water vapor (H₂O), another substance emitted by new motor vehicles and engines that is also considered a powerful GHG. Considered in isolation, H₂O concentrations in the atmosphere can be said to endanger public health or welfare by resulting in rain that leads to slip-and-fall injuries, drownings, and damage to crops, livestock, and property, including through pools, rivers, and floodwater, although water vapor is not itself harmful and is necessary to sustain life. Also considered in isolation, CAA section 202(a) sources can be said to “contribute” to elevated H₂O concentrations in the atmosphere from all anthropogenic sources, and these emissions of water vapor would thereby assertedly “contribute” to global climate effects similar to those attributed to other GHGs. CAA section 202(a) does not contemplate prescribing emission standards for such an omnipresent, naturally occurring, and essential component of the ambient air, and stakeholders have not petitioned for such regulation, because the text requires analyzing the extent to which emissions contribute to the danger. The logic of regulating water vapor would appear to be absurd, but it is the same logic required to regulate GHGs under CAA section 202(a).

We further propose that the decision to sever the analysis of endangerment from the analysis of contribution, combined with the decision to sever the Administrator’s findings from any standards prescribed as a result, produced an analysis that is incompatible with the statute. In the Endangerment Finding, the Administrator concluded that anything more than a trivial or *de minimis*

⁶⁵ 42 U.S.C. 7411(a)(1), (b)(1)(B). CAA section 111 also differentiates between new and existing stationary sources in a listed source category and limits the EPA’s role with respect to existing sources by authorizing only emission guidelines implemented by the States. 42 U.S.C. 7411(d).

⁶⁷ U.S. Environmental Protection Agency. (Last updated Jan. 16, 2025). Understanding Global Warming Potentials: <https://www.epa.gov/ghgemissions/understanding-global-warming-potentials>.

⁶⁸ 42 U.S.C. 7521(a)(1) (emphases added).

⁶⁹ For additional discussion of improvements in new motor vehicles and engines relative to older vehicles and engines, see section V of this preamble.

⁶⁵ 42 U.S.C. 7411(b)(1)(A).

contribution to elevated global GHG concentrations by CAA section 202(a) sources was sufficient to trigger regulation because the “unique, global aspects of the climate change problem tend to support contribution at lower percentage levels of emissions than might otherwise be considered appropriate when addressing a more typical local or regional air pollution problem.” 74 FR 66538. Because the Endangerment Finding did not consider the standards that the statute requires when the Administrator makes such a finding, we did not consider whether emission standards for new motor vehicles would be futile as a means to address the identified dangers of GHG emissions from all anthropogenic sources. As discussed in sections IV.A and IV.B of this preamble, reducing GHG emissions from all vehicles and engines in the United States to zero would not have a scientifically measurable impact on GHG emission concentrations or global warming potential (2025 CWG Draft Report at 130).⁷⁰ It was foreseeable at the time that issuing the Endangerment Finding would trigger a duty to regulate, and that extraordinarily stringent measures would be necessary under *all* of the EPA’s separate statutory authorities, and not just CAA section 202(a), to have *any* potentially measurable impact on the identified harm. Additionally, the EPA did not consider “carbon leakage,” which “refers to the situation that may occur if, for reasons of costs related to climate policies, businesses were to transfer production to other countries with laxer emission constraints . . . [and] could lead to an increase in their total emissions.”⁷¹ Foreign governments have recognized that carbon leakage can mitigate or even lead to an increase in total emissions which would significantly impact the claimed benefits of the regulatory actions.⁷² Accordingly, we propose that refusing to consider these foreseeable consequences was inconsistent with the statutory scheme and, as explained further below, arbitrary and capricious and an abuse of discretion.

Finally, we propose that the Administrator did not adequately consider the meaning in context of the statutory term “endanger” and failed to identify with sufficient rigor the purported danger linked to GHG

emissions from new motor vehicles and engines. We propose that “endanger” as used in CAA section 202(a) cannot mean merely any predicted negative impact to any public health or welfare value, as that interpretation would render the constraint placed on the EPA’s authority to prescribe standards essentially meaningless, thereby violating ordinary principles of statutory interpretation and raising constitutional nondelegation concerns. We further propose that severing the endangerment and contribution inquiries improperly allowed the Administrator to avoid this concern by concluding that new motor vehicle and engine emissions included more than *de minimis* GHG emissions, even if those emissions did not themselves contribute to a danger in any meaningful sense. *See* 74 FR 66543 (asserting that “contributors must do their part even if their contributions to the global problem, measured in terms of percentage, are smaller than typically encountered”). We therefore seek comment on whether this aspect of EPA’s interpretation and application of the statutory provision in 2009 was defective and whether, either on its own or in combination with the other bases and rationales presented here, this issue provides additional grounds for rescinding the Endangerment Finding and resulting GHG emission standards for new motor vehicles and engines.

2. Lack of Clear Congressional Authorization

The EPA further proposes that, at a minimum and in addition to the interpretation set out above, we lack the “clear congressional authorization” required under the major questions doctrine to decide the Nation’s response to global climate change concerns. *West Virginia*, 597 U.S. at 723 (quoting *UARG*, 573 U.S. at 324). In this subsection, we propose that the major questions doctrine applies to the Endangerment Finding because the global climate change concerns addressed in that action, and the mandatory duty to regulate triggered by that action, present a major question of undeniable political and economic significance. Next, we propose that Congress did not clearly authorize the EPA to decide this question when it empowered the Administrator to “prescribe . . . standards” for new motor vehicle and engine emissions under CAA section 202(a). On that basis, we propose to conclude that the Endangerment Finding and resulting GHG emission standards exceeded our statutory authority and should be rescinded. That conclusion follows from

the Supreme Court’s decisions in *UARG* and *West Virginia* and is consistent with *Massachusetts*, which held that GHGs fell within the definition of “air pollutant” but did not interpret the scope of our authority to regulate air pollutants that cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare.

Applicability of the Major Questions Doctrine. In recent decisions construing the scope of the EPA’s statutory authority to regulate GHGs, the Supreme Court has emphasized that the “‘history and breadth of the authority’” asserted by an agency and “‘the ‘economic and political significance’ of that assertion” provide “‘a reason to hesitate before concluding that Congress’ meant to confer such authority.” *West Virginia*, 597 U.S. at 721 (quoting *Brown & Williamson*, 529 U.S. at 159–60); *accord UARG*, 573 U.S. at 324. Whether viewed as an ordinary tool of statutory interpretation that looks to the structure of the regulatory scheme⁷³ or a clear statement rule that implements nondelegation and separation of power principles,⁷⁴ the major questions doctrine requires us to identify “more than a merely plausible textual basis” when asserting authority to decide a significant policy issue on Congress’ behalf. *Id.* at 723.

In *UARG*, the Supreme Court applied the major questions doctrine to reject our attempt to regulate GHG emissions from stationary sources subject to the CAA’s prevention of significant deterioration (PSD) and Title V permitting requirements based on the global climate change concerns identified in the Endangerment Finding. 573 U.S. at 311–13.⁷⁵ The Court held that the EPA had “exceeded its statutory authority when it interpreted the Clean Air Act to require PSD and Title V permitting for stationary sources based on their greenhouse gas emissions” and “may not treat greenhouse gases as a pollutant” in the PSD and Title V contexts. *Id.* at 333. In reaching this conclusion, the Court found that our interpretation of the statute and related “tailoring rule” that exempted many sources to address workability concerns was “unreasonable because it would bring about an enormous and transformative expansion in EPA’s regulatory authority without clear congressional authorization.” *Id.* at 324. Citing earlier major questions doctrine

⁷⁰ See Lomborg, B. (2016). Impact of Current Climate Proposals. *Global Policy*, 7(1) 109–118: <https://doi.org/10.1111/1758-5899.12295>.

⁷¹ Carbon leakage. (2019). *European Commission*: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/free-allocation/carbon-leakage_en.

⁷² *See, e.g., id.*

⁷³ *Biden v. Nebraska*, 600 U.S. 477, 507–21 (2023) (Barrett, J., concurring).

⁷⁴ *West Virginia*, 597 U.S. at 735–51 (Gorsuch, J., concurring).

⁷⁵ *See* 42 U.S.C. 7470–92, 7661 *et seq.*

precedents, the Court noted that “a measure of skepticism” is required when “an agency claims to discover in a long-extant statute an unheralded power to regulate ‘a significant portion of the American economy,’ ” *id.* (quoting *Brown & Williamson*, 529 U.S. at 159), and that “[w]e expect Congress to speak clearly if it wishes to assign to an agency decisions of vast ‘economic and political significance,’ ” *id.* (quoting *Brown & Williamson*, 529 U.S. at 160).

In *West Virginia*, the Supreme Court again applied the major questions doctrine to reject our attempt to shift the power grid away from using fossil fuels through GHG emission guidelines for existing power plants under CAA section 111(d). 597 U.S. at 711–15.⁷⁶ The Court noted that when interpreting a grant of regulatory authority, the inquiry includes the question “whether Congress in fact meant to confer the power the agency has asserted.” *Id.* at 721. The Court explained that the major questions doctrine applies when “the ‘history and breadth of the authority that [the agency] has asserted,’ and the ‘economic and political significance’ of that assertion, provide ‘a reason to hesitate before concluding that Congress’ meant to confer such authority.’ ” *Id.* (quoting *Brown & Williamson*, 529 U.S. at 159–60). In such cases, “both separation of powers principles and a practical understanding of legislative intent make us ‘reluctant to read into ambiguous statutory text’ the delegation claimed to be lurking there,” and “[t]he agency instead must point to ‘clear congressional authorization’ for the power it claims.” *Id.* at 723 (quoting *UARG*, 573 U.S. at 324). Applying that standard, the Court held that our statutory authority to establish emission limits under CAA section 111(a)(1) and (d) “is not close to the sort of clear authorization required by our precedents.” *Id.* at 732.

We propose that the Endangerment Finding implicates the major questions doctrine for the same reasons the Supreme Court applied it in *UARG* and *West Virginia*. By asserting jurisdiction to regulate in response to global climate change concerns, the EPA “‘claim[ed] to discover in a long-extant statute an unheralded power’ representing a ‘transformative expansion in [its] regulatory authority.’ ” *West Virginia*, 597 U.S. at 724 (quoting *UARG*, 573 U.S. at 324). We note that the regulatory

actions reviewed in *UARG* and *West Virginia* were predicated in part on the Endangerment Finding and propose that the PSD and Title V rules in *UARG* and existing source emission guidelines in *West Virginia* are similar in scope, approach, and economic impact as the GHG emission standards for new motor vehicles and engines promulgated to fulfill the mandatory duty triggered by the Endangerment Finding. As a consequence of the novel approach taken in the Endangerment Finding to endangerment and contribution, our GHG emission standards mandate an increased and faster shift from gasoline-fueled vehicles to electric vehicles on the theory that a substantial reduction in GHG emissions is necessary to address global climate change concerns.⁷⁷ We propose that mandating a shift in the national vehicle fleet from one type of vehicle to another is indistinguishable from the emission guidelines at issue in *West Virginia*, which were calculated to force a shift from one means of electricity generation to another.

We further propose it is “‘highly unlikely that Congress would leave’ to ‘agency discretion’ the decision” of how much gasoline should be used by vehicles and engines in the United States. *West Virginia*, 597 U.S. at 729 (quoting *MCI Telecomms. Corp. v. AT&T Co.*, 512 U.S. 218, 231 (1994)). As the Supreme Court noted with respect to coal-based electricity generation, such a policy decision involves “basic and consequential tradeoffs,” and “Congress certainly has not conferred a like authority upon EPA anywhere else in the Clean Air Act.” *Id.* Until the Endangerment Finding, moreover, we had never invoked CAA section 202(a) or any other CAA authority to regulate in response to global climate change concerns, whether through a fuel-shifting strategy or any other means. That history is telling because although CAA section 202(a) has existed in substantially similar form since 1967, “the EPA had never regulated in that manner, despite having issued many prior rules governing” vehicle and engine emissions. *Id.*

When Congress has addressed GHGs individually or collectively, it has not granted the EPA broad regulatory authority comparable to our authority to “‘prescribe . . . standards” under CAA section 202(a). With respect to HFCs, Congress enacted a comprehensive phaseout scheme in the 2020 American Innovation and Manufacturing (AIM) Act, which includes detailed instructions, timelines, and

requirements for implementation and allows some uses to continue under certain conditions.⁷⁸ With respect to CO₂, Congress opted for a carrot rather than a stick by authorizing a tax credit to incentivize underground sequestration that mitigates emissions.⁷⁹ With respect to methane, Congress amended the CAA in 2021 through the Inflation Reduction Act of 2022 (IRA) to require us to establish a waste emissions charge for certain sources structured to incentivize emissions reductions over time.⁸⁰ When addressing GHGs more generally, Congress has used non-regulatory tools that incentivize, rather than mandate, changes in private ordering, including through additional funding provisions in the IRA.⁸¹ We propose that multiple instances of recent legislation addressing GHGs individually and through distinct regulatory approaches suggests that Congress views such policy decisions as economically and politically significant and not adequately addressed by general statutory authorities enacted in response to different problems.

The EPA notes that Congress has continued to revise these air pollutant-specific measures and nonregulatory tools as part of an ongoing national debate over the appropriate response to global climate change concerns. On July 4, 2025, President Trump signed into law significant new legislation enacted by Congress, the One Big Beautiful Bill Act (OBBA),⁸² which repealed a number of relevant measures adopted in the IRA and rescinded the EPA’s appropriations to carry out a number of funding programs related to GHG emissions. Among other things, Congress prohibited the Agency from collecting the waste emission charge for methane for ten years beyond the original statutory collection date, rescinded funding to administer grant programs in CAA sections 132 and 135–38, and repealed CAA section 134, which had included a section-specific definition of “greenhouse gas” applicable to the grant

⁷⁸ Public Law 116–260, Div. S, codified at 42 U.S.C. 7675 *et seq.*

⁷⁹ 26 U.S.C. 45Q. In 2020, Congress also instructed us to recommend improvements to SDWA permitting procedures for injection wells used in carbon sequestration and appropriated additional fundings for the “Class VI” permitting process. Public Law 116–260, Div. G, Title II.

⁸⁰ Public Law 117–169, codified at 42 U.S.C. 7436.

⁸¹ See, e.g., Public Law 117–169, codified at 42 U.S.C. 7432–7438. We also note that CAA section 211(o)(2)(B)(ii) requires the EPA to consider “the impact of the production and use of renewable fuels on the environment, including on . . . climate change,” among many other factors, in setting volumes under the RFS program. 42 U.S.C. 7545(o)(2)(B)(ii).

⁸² Public Law 119–21.

⁷⁶ See 42 U.S.C. 7411(d). The EPA had also issued GHG performance standards for new and modified fossil fuel-fired power plants under CAA section 111(b) that triggered the Agency’s authority to issue guidelines for existing sources under CAA section 111(d). The new source standards were not before the Supreme Court in *West Virginia*.

⁷⁷ 89 FR 27842, 27844.

program set out in that section.⁸³ We propose that this legislation, which was the product of substantial national debate and revised and rescinding funding for provisions of the IRA that were themselves the product of substantial national debate, indicates that the EPA erred in attempting to resolve significant policy issues on its own accord in the Endangerment Finding.

Congress has also recently disapproved several actions taken by the EPA with respect to GHG emissions. On May 19, 2025, President Trump signed into law a resolution adopted by Congress under the Congressional Review Act (CRA) to void our final rule implementing the waste emission charge added to the CAA in 2021.⁸⁴ And on June 12, 2025, President Trump signed into law three resolutions adopted by Congress under the CRA to void waivers we granted under CAA section 209 that allowed California and participating States to enforce GHG emission regulations for motor vehicles and engines, up to and including zero-emissions standards that mandated a shift to electric vehicles.⁸⁵ We propose that these disapproval resolutions further demonstrate the economic and political significance of the EPA's GHG emission regulations and reinforce the understanding that Congress intends to reserve such major questions of policy for itself. See *West Virginia*, 597 U.S. at 731–32.

Proposed Conclusion. Under our proposal that the major questions doctrine applies, we propose to conclude that the EPA lacks the “clear congressional authorization” required for the novel approach taken in the Endangerment Finding and resulting GHG emission standards and must rescind these actions. *West Virginia*, 597 U.S. at 723 (quoting *UARG*, 573 U.S. at 324). We propose that our statutory authority under CAA section 202(a) to “prescribe . . . standards” does not clearly authorize the EPA to regulate in response to global climate change concerns or, in issuing such regulations, to mandate a shift from gasoline-powered vehicles to electric vehicles.

In *West Virginia*, the Supreme Court held that our authority “to establish emission caps at a level reflecting ‘the application of the best system of

emission reduction . . . adequately demonstrated’” did not clearly authorize the EPA to issue emission guidelines that addressed global climate change concerns by mandating a shift away from coal-generated electricity. 597 U.S. at 732. Similarly, in *UARG*, the Court held that our PSD and Title V authorities could not be extended to GHG emissions because those provisions “are designed to apply to, and cannot rationally be extended beyond, a relative handful of large sources capable of shouldering heavy substantive and procedural burdens.” 573 U.S. at 303.

We propose that these cases control the analysis of our authority under CAA section 202(a). As in *West Virginia*, our statutory authority and the findings required to invoke that authority do not clearly authorize the approach taken in the Endangerment Finding and subsequent regulations. And as in *UARG*, our statutory authority to “prescribe . . . standards” for emissions of certain air pollutants does not clearly authorize using the CAA’s vehicle-emission control scheme to address global climate change. As discussed above, the Endangerment Finding did not limit itself to considering the impacts of GHG emissions from new motor vehicles and engines. Rather, the Endangerment Finding reviewed the totality of adverse impacts from climate change attributed to all anthropogenic sources of GHG emissions worldwide and asserted jurisdiction over CAA section 202(a) sources by finding they contributed to such impacts by emitting more than *de minimis* quantities of GHGs. That understanding has permeated our GHG emission rulemakings since 2009, and we have attempted to apply that framework to our distinct regulatory authorities for stationary sources and aircraft.

In *Massachusetts*, the Supreme Court disagreed with the EPA’s argument that GHGs were not “air pollutants” because Congress had not revisited CAA section 202(a) in amending the CAA in 1990. 549 U.S. at 512–13. The Court found that our reliance on *Brown & Williamson* to support that argument was misplaced because unlike the ban on tobacco products at issue in that case, “EPA jurisdiction would lead to no such extreme measures.” *Id.* at 531. The Court also found that unlike the Food and Drug Administration’s earlier statements on tobacco products, “EPA had never disavowed the authority to regulate greenhouse gases” and had issued a memorandum in 1998 suggesting that we had such authority. *Id.*

We propose that *Massachusetts* did not consider or have reason to interpret the scope of the EPA’s authority under CAA section 202(a) given our position in the 2003 Denial that GHGs are not “air pollutant[s]” under any provision of the statute. Rather, we propose *Massachusetts* rejected our position that GHGs are “categorically” excluded from the CAA and remanded for the Administrator to determine whether four GHGs met the standard in CAA section 202(a). *UARG*, 573 U.S. at 320. We further propose that *Massachusetts* must be read together with the Supreme Court’s decisions in *West Virginia* and *UARG*, which applied the major questions doctrine to statutory provisions similar to CAA section 202(a). To that end, we seek comment on whether *Massachusetts* applied the major questions doctrine in the first instance,⁸⁶ and, if it did, whether that analysis informs the meaning of CAA section 202(a) on its own terms and in light of *UARG* and *West Virginia*. Finally, we propose that the EPA’s course of rulemaking has not been limited to emission standards as anticipated in *Massachusetts*. We seek comment on whether a new major questions doctrine analysis is required because the EPA’s rulemakings in response to the Endangerment Finding have included electric vehicle mandates that require shifting the national vehicle fleet from one type of vehicle and vehicle fuel to another.

B. Alternative Rationale for Proposed Rescission

In the alternative, the EPA proposes that even if CAA section 202(a) could be read to authorize prescribing GHG emission standards for new motor vehicles and engines, the Endangerment Finding unreasonably applied the statutory standard for regulation to the scientific record and should be rescinded on that basis. This subsection proposes several reasons that the Administrator would exercise his discretionary judgment differently today in light of intervening legal and scientific developments that appear to undermine the assumptions, methodologies, and conclusions of the Endangerment Finding.

1. Climate Science Discussion

The Administrator reviewed available information, including the most recently available scientific information, bearing on the assumptions and conclusions in

⁸³ 42 U.S.C. 7434(c)(2) (2022).

⁸⁴ Public Law 119–2; see 90 FR 21225 (May 19, 2025).

⁸⁵ H.J. Res. 87; H.J. Res. 88; H.J. Res. 89; see also *Diamond Alt. Energy, LLC v. EPA*, No. 24–7, slip op. at 4 n.1 (U.S. June 20, 2025); Statement by the President (June 12, 2025); <https://www.whitehouse.gov/briefings-statements/2025/06/statement-by-the-president/>.

⁸⁶ We note that recent Supreme Court decisions have not cited *Massachusetts* as a precedent applying, or declining to apply, the major questions doctrine. See, e.g., *Nebraska*, 600 U.S. 477; *West Virginia*, 597 U.S. 697.

the Endangerment Finding, the impacts of global GHG concentrations on public health and welfare in the United States, and the relative contribution of domestic emissions from new motor vehicles and engines to global GHG concentrations. As previously explained, this review included the 2025 CWG Draft Report, which analyzes empirical data, peer-reviewed studies, and available scientific information bearing on direct human influence on ecosystems and climate, climate response to CO₂ emissions, and impacts on ecosystems and society.⁸⁷ The Administrator also considered available assessments by the U.S. Government and relevant international bodies, including the Third, Fourth, and Fifth NCAs reported by the USGCRP and AR5 and AR6 by the United Nations IPCC. The Administrator also considered critiques of the NCAs, and the Fifth NCA in particular, and reviewed these analyses for consistency with OMB information quality guidelines⁸⁸ and the transparency and reliability requirements of Executive Order 14303, “Restoring Gold Standard Science.”⁸⁹

The Endangerment Finding itself acknowledged significant uncertainties related to climate change and its potential impacts when it stated that the “inherent uncertainty in the direction, magnitude and/or rate of certain future climate change impacts opens up the possibility that some changes could be more or less than expected, and the possibility of unanticipated outcomes.” 74 FR 66524. Specifically, the Endangerment Finding identified uncertainties including, but not limited to: the net health impacts of a temperature increase due to decreases in cold-related mortality, 74 FR 66497, 66526; increases in allergenic illnesses and pathogen borne disease vectors, 74 FR 66498; food production and crop yields, including the scope of potential beneficial impacts from climate change, 74 FR 66498, 66535; temperature at the end of the 21st Century, 74 FR 66519; records of temperature before 1600 A.D., 74 FR 66523; estimates and future projections of anthropogenic aerosols

and their respective heating or cooling effects, 74 FR 66519; the extent to which human-induced climate change affects the intensity and frequency of extreme weather events, 74 FR 66531; and emissions from future fleet motor vehicles, which could be impacted by a number of technological, economic, and independent regulatory factors, 74 FR 66543.

With respect to projected increases in GHG concentrations and global temperatures, the projections relied upon in the Endangerment Finding appear unduly pessimistic in light of empirical observations made after it was finalized in 2009 through 2024. The Endangerment Finding relied primarily on IPCC AR4 to predict global temperature increases between 1.8 and 4 degrees Celsius by 2100, an extremely wide and variable range that necessarily impacts the existence, extent, and severity of anticipated dangers to public health and welfare. 74 FR 66519. However, as previously noted, IPCC scenarios depicting worst-case, “business as usual” assessments have been criticized as misleading (2025 CWG Draft Report at 16),⁹⁰ and empirical data suggest that actual GHG emission concentration increase and corresponding warming trends through 2025 have tracked the IPCC’s more optimistic scenarios (2025 CWG Draft Report at 18).⁹¹ Recent scientific analyses propose that this divergence may be explained by greater capacity for the climate to reuptake GHGs in the atmosphere through natural processes. Terrestrial ecosystems have demonstrated a greater than anticipated sensitivity to elevated CO₂ concentrations in the form of enhanced plant growth, which results in greater

removal of CO₂ from the atmosphere as plants take up CO₂ and return it to the soil through natural life cycles. Similarly, the oceans have demonstrated a greater capacity to take up and process CO₂ (including through aquatic plant life) without resulting in the anticipated negative impacts on pH and ocean ecosystems, including coral reefs (2025 CWG Draft Report at 6–9, 18–20).⁹²

Relatedly, recent empirical data and analyses suggest that the Endangerment Finding was unduly pessimistic in attributing health risks from heat waves to increases in global temperature. Notwithstanding increased public attention to heat waves, the data suggest that domestic temperatures peaked in the 1930s and have remained more or less stable, in relative terms, since those highs (2025 CWG Draft Report at 57–60). Moreover, increased urbanization trends contribute to localized changes in temperature, including because an urban footprint traps heat and frustrates natural heat-cycling capacity at a localized and low-atmospheric level (2025 CWG Draft Report at 21–22). Contrary to the Endangerment Finding’s assumptions, data continue to suggest that mortality risk from cold temperatures remains by far the greater threat to public health in the United States and around the world at the aggregate level (2025 CWG Draft Report at 112).⁹³ Although the risk of heat waves featured prominently in the Endangerment Finding, the Administrator acknowledged at the time that significant uncertainties existed about the relative benefits and risks in the United States, and the data since 2009 suggest that the balance of climate change as a whole appears to skew

⁹² See also Browman, H.I. (2016). Applying organized skepticism to ocean acidification research. *ICES Journal of Marine Science*, 73(3), 529.1–536: <https://doi.org/10.1093/icesjms/fsw010>; Clements, J.C. et al. (2022). Meta-analysis reveals an extreme “decline effect” in the impacts of ocean acidification on fish behavior. *PLOS Biology*, 20(2), e3001511: <https://doi.org/10.1371/journal.pbio.3001511>; Friedlingstein, P. et al. (2024). Global Carbon Budget 2024. *Earth System Science Data*, 14(4): <https://essd.copernicus.org/preprints/essd-2024-519>; Haverd, V. et al. (2020). Higher than expected CO₂ fertilization inferred from leaf to global observations. *Global Change Biology*, 26, 2390–2402: <https://doi.org/10.1111/gcb.14950>; Zeng, Z. et al. (2017). Climate mitigation from vegetation biophysical feedbacks during the past three decades. *Nature Climate Change*, 7, 432–436: <https://doi.org/10.1038/nclimate3299>.

⁹³ See also Zhao, Q. et al. (2021). Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study. *The Lancet Planetary Health*, 5(7): [https://doi.org/10.1016/s2542-5196\(21\)00081-4](https://doi.org/10.1016/s2542-5196(21)00081-4); Gasparini, A. et al. (2015). Mortality risk attributable to high and low ambient temperature: a multicounty observational study. *The Lancet*, 386(9991), 369–375: [https://doi.org/10.1016/S0140-6736\(14\)62114-0](https://doi.org/10.1016/S0140-6736(14)62114-0).

⁸⁷ As stated earlier, the 2025 CWG Draft Report was provided to the EPA on May 27, 2025, and was reviewed and relied upon in formulating this proposal. The EPA understands that DOE is releasing an updated version of the CWG draft report and seeking public comment on the updated report, which includes additional information and typographical corrections that the EPA did not rely upon in formulating this proposal. Interested parties may review and comment on the updated version of the CWG draft report for consideration as part of DOE’s efforts at <https://www.energy.gov/topics/climate>.

⁸⁸ 67 FR 8452 (Feb. 22, 2002).

⁸⁹ Executive Order 14303, 90 FR 22601 (May 29, 2025).

⁹⁰ See also Hausfather, Z. & Peters, G.P. (2020). Emissions—the ‘business as usual’ story is misleading. *Nature*, 577, 618–620: <https://doi.org/10.1038/d41586-020-00177-3>; Burgess, M.G. et al. (2021). IPCC baseline scenarios have over-projected CO₂ emissions and economic growth. *Environmental Research Letters*, 16, 014016: <https://doi.org/10.1088/1748-9326/abcd22>; Pielke, R., & Ritchie, J. (2020). Systemic Misuse of Scenarios in Climate Research and Assessment Social Sciences Research Network. SSRN: <http://doi.org/10.2139/ssrn.3581777>.

⁹¹ See also Hausfather, Z. et al. (2019). Evaluating the Performance of Past Climate Model Projections. *Geophysical Research Letters*, 47(1): <https://doi.org/10.1029/2019GL085378>; Scaffeta, N. (2023). CMIP6 GCM ensemble members versus global surface temperatures. *Climate Dynamics*, 60, 3091–3120: <https://doi.org/10.1007/s00382-022-06493-w>; McKittrick, R. & Christy, J. (2020). Pervasive Warming Bias in CMIP6 Tropospheric Layers. *Earth and Space Science*, 7(9), e2020EA001281: <https://doi.org/10.1029/2020EA001281>; Karl, T.R. et al. (2006). *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. U.S. Climate Change Science Program, Subcommittee on Global Change Research.

substantially more than previously recognized by the EPA in the direction of net benefits, or is at least too uncertain to establish a credible and reliable finding of actionable risk, as discussed further below.

With respect to extreme weather events, the Endangerment Finding projected adverse health impacts from increased frequency and severity of hurricanes, flooding, and wildfires. *E.g.*, 74 FR 66498. Recent data and analyses suggest, however, that despite increased public attention and concern, such extreme weather events have not demonstrably increased relative to historical highs (2025 CWG Draft Report at 65–72, 111).⁹⁴ In reviewing the assumptions and conclusions regarding extreme weather events in the Endangerment Finding, the empirical bases asserted appear to be more generalized and unsupported than previously believed and no longer inspire the same degree of confidence. The Administrator further notes that the risks anticipated in the Endangerment Finding resulted, in part, from the Agency's decision at the time to categorically exclude consideration of adaptation and mitigation that should have been incorporated into the analysis as credible and relevant information. We propose that the data on weather events, coupled with the Agency's decision to exclude mitigation and adaptation information from the analysis, fatally undermines the Endangerment Finding's conclusions in this respect.

The Endangerment Finding also identified public health and welfare impacts from projected increases in sea level and related weather and climatic events. However, on this issue, too, recent data and analyses suggest that aggregate sea level rise has been minimal, at least with respect to impacts

on the United States, and that sea level has risen in some domestic localities while falling in others (2025 CWG Draft Report at 75–80). The Administrator also questions whether it was appropriate for the Endangerment Finding to exclude any analysis of adaptation with respect to sea level rise in particular. Population growth, infrastructure development, and local and regional planning decisions have been dynamic in coastal areas since 2009, with different trends in different coastal areas and different choices made independently of the EPA's regulatory actions by state and local governments and private entities. The lack of analysis of adaptation generally, and particularly with respect to sea level rise, reduces confidence in the reasonableness, accuracy, and reliability of the assumptions and conclusions in the Endangerment Finding.

The difficulties with parsing the scientific record continue, and they go to the root of what methodologies should be given most credence in making any scientific determinations. The Endangerment Finding consistently cites climate models as showing or predicting warming trends, melting ice, anthropogenic droughts, shrinking snowpack, damage to aquatic systems of life, and increased ocean temperature and acidity. *E.g.*, 74 FR 66523, 66532. However, the data relied upon as inputs to these models may be based on inaccurate assumptions. (2025 CWG Draft Report at 14–22).⁹⁵ To name but a few instances: the Northern hemispheric winter snow cover has not decreased in line with the models used in the Endangerment Finding; aquatic life is largely adapted for and has undergone oceanic pH changes throughout the Earth's history, and the data used by the Endangerment Findings and predictions of coral decline has not been supported by empirical data showing an unexpected growth in coral reef ecosystems (2025 CWG Draft Report at 7–12, 40–41).⁹⁶ In addition, the models relied upon by the Endangerment Finding may be incorrect with regard to warming in the U.S. Corn Belt given the

divergence of recent empirical data from projected trends (2025 CWG Draft Report at 32–47).

The Administrator is also troubled by the Endangerment Finding's seemingly inconsistent treatment of the nature and extent of the role human action with respect to climate change. The Endangerment Finding attributes the entirety of adverse impacts from climate change to increased GHG concentrations, and it attributes virtually the entirety of increased GHG concentrations to anthropogenic emissions from all sources. But the causal role of anthropogenic emissions is not the exclusive source of these phenomena, and any projections and conclusions bearing on the issue should be appropriately discounted to reflect additional factors. Moreover, recent data and analyses suggest that attributing adverse impacts from climate change to anthropogenic emissions in a reliable manner is more difficult than previously believed and demand additional analysis of the role of natural factors and other anthropogenic factors such as urbanization and localized population growth (2025 CWG Draft Report at 14–22, 82–92).⁹⁷

In addition, and as noted in particular contexts above, the Administrator is concerned that the Endangerment Finding did not adequately balance the projected adverse impacts attributed to global climate change with the potential benefits to the United States of increased GHG concentrations, and increased CO₂ concentrations in particular. Unlike virtually every other gas regulated under the CAA, CO₂ is necessary for human, animal, and plant life, and advances public health and welfare by directly impacting plant growth and therefore the price and availability of food, the success of American agricultural and related

⁹⁴ See also Masson-Delmotte, V. et al. (2021) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: <https://doi.org/10.1017/9781009157896>; Klotzbach, P.J. et al. (2018). Continental U.S. Hurricane Landfall Frequency and Associated Damage: Observations and Future Risks. *Bulletin of the American Meteorological Society*, 99(7), 1359–1376: <https://doi.org/10.1175/BAMS-D-17-0184.1>; Hodgkins, G.A. et al. (2017). Climate-driven variability in the occurrence of major floods across North America and Europe. *Journal of Hydrology*, 552, 704–717: <https://doi.org/10.1016/j.jhydrol.2017.07.027>; Wuebbles, D.J. et al. (2017). Climate Science Special Report: Fourth National Climate Assessment, Volume I. U.S. Global Change Research Program: <http://doi.org/10.7930/J0J964J6>; Hodgkins, G.A. et al. (2017). Climate-driven variability in the occurrence of major floods across North America and Europe. *Journal of Hydrology*, 552, 704–717: <https://doi.org/10.1016/j.jhydrol.2017.07.027>.

⁹⁵ See also McKittrick, R. et al. (2012). Long-Term Forecasting of Global Carbon Dioxide Emissions: Reducing Uncertainties Using a Per Capita Approach. *Journal of Forecasting*, 32(5), 435–451: <https://doi.org/10.1002/for.2248>.

⁹⁶ See also Connolly, R. et al. (2019). Northern Hemisphere Snow-Cover Trends (1967–2018): A Comparison between Climate Models and Observations. *Geosciences*, 9(3), 135: <https://doi.org/10.3390/geosciences9030135>; Annual Summary Report of Coral Reef Condition 2021/22. Continued coral recovery leads to 36-year highs across two-thirds of the Great Barrier Reef. (2022). Australian Institute of Marine Science: <https://www.aims.gov.au/monitoring-great-barrier-reef/gbr-condition-summary-2021-22>.

⁹⁷ McKittrick, R. (2013). Encompassing tests of socioeconomic signals in surface climate data. *Climatic Change*, 120(1–2), 95–107: <https://doi.org/10.1007/s10584-013-0793-5>; McKittrick, R. & Nierenberg, N. (2010). Socioeconomic Patterns in Climate Data. *Journal of Economic and Social Measurement*, 35(3–4), 149–175: <https://doi.org/10.3233/JEM-2010-0336>; McKittrick, R. (2021). Checking for model consistency in optimal fingerprinting: a comment. *Climate Dynamics*, 58(1–2), 405–411: <https://doi.org/10.1007/s00382-021-05913-7>; McKittrick, R. (2023). Total least squares bias in climate fingerprinting regressions with heterogeneous noise variances and correlated explanatory variables. *Environmetrics*, 35(2), e2835: <https://doi.org/10.1002/env.2835>; McKittrick, R. (2022). On the choice of TLS versus OLS in climate signal detection regression. *Climate Dynamics*, 60, 359–374: <https://doi.org/10.1007/s00382-022-06315-z>; Connolly, R. et al. (2021). How much has the sun influenced Northern Hemisphere temperature trends? An ongoing debate. *Research in Astronomy and Astrophysics*, 21(6), 131: <https://doi.org/10.1088/1674-4527/21/6/131>.

industries, and the traditional capacity of the United States to export significant food supplies around the world for economic and humanitarian purposes. Recent data and analysis show that even marginal increases in CO₂ concentrations have substantial beneficial impacts on plant growth and agricultural productivity, and that this benefit has been significantly greater than previously believed (2025 CWG Draft Report at 6–7, 104–09).

The Administrator also questions the decision in the Endangerment Finding to consider together all six “well-mixed” GHGs rather than analyzing the properties and impacts of each on an individual basis. 74 FR 66537. As noted in the 2008 ANPRM, new motor vehicle and engine emissions of the four GHGs they actually emit have fluctuated and diverged over time, and each has different interactions with the climate and natural environment. Nevertheless, the Endangerment Finding did not undertake individual analyses of these four GHGs and, in fact, aggregated them together along with two additional GHGs not emitted by motor vehicles or motor vehicle engines, thereby undermining the transparency, reliability, and usefulness of the findings. We propose that each of the collectively treated GHGs demonstrates different chemical properties, exhibits different interactions with the natural environment, and present different emissions profiles. The Agency did not analyze, for example, whether the three GHGs other than CO₂ emitted by new motor vehicles and engines could be addressed separately in a manner that would impact the ultimate conclusions of endangerment and contribution. Nor did the Agency analyze whether HFCs, which are emitted not by engines but by air conditioning units, could be addressed separately under CAA section 202(a) or another authority in a manner that would impact the ultimate conclusions of endangerment and contribution.

Finally, the Administrator notes that the analyses relied upon in the Endangerment Finding, including the assessment reports of the IPCC and USGCRP that were available at the time and the subsequent iterations of those reports that have been published since 2009, have been criticized on process and quality grounds. Recently, several public watchdog organizations have raised concerns related to the process and quality of the Fifth NCA, which shares the underlying assumptions and conclusions of prior NCAs and IPCC reports. The groups state that NCA5 does not meet the requirements under Executive Order 14303 and deviated

from OMB guidelines on quality, objectivity, utility, and integrity of information disseminated by Federal agencies.

The Administrator takes each of these concerns seriously and seeks public comment on the validity of these concerns and how they should be taken into account when determining whether to finalize any of the alternatives proposed in this action.

2. Proposed Conclusions

Based on this review of the Endangerment Finding and the most recently available scientific information, data, and studies, the Administrator proposes to find, in an exercise in discretionary judgment, that there is insufficient reliable information to retain the conclusion that GHG emissions from new motor vehicles and engines in the United States cause or contribute to endangerment to public health and welfare in the form of global climate change. This proposed conclusion is animated both by the Administrator’s commitment to analyzing the statutory standard as a cohesive whole and by the scientific record, which includes too many analytical gaps, uncertainties, and speculative predictions to reach an affirmative endangerment finding and promulgate corresponding emission standards based on such a finding.

As explained above, the Administrator previously asserted in the Endangerment Finding that CAA section 202(a) grants “procedural discretion” to sever the findings that trigger regulation from consideration of the resulting regulations and to sever the endangerment analysis from the causation or contribution analysis. We propose that the Administrator would now exercise such discretion differently to ensure greater reliability, transparency, and public accountability in the EPA’s invocation of regulatory authority. We note that as a result of the approach taken in the Endangerment Finding, the Administrator’s conclusions with respect to new motor vehicles and engines were never subject to SAB review as required by the CAA, and that the public never had the opportunity to participate in a rulemaking that paired the consideration of risk with discussion of the regulatory response, including the effectiveness and cost of potential regulatory approaches. We propose that CAA section 202(a) operates as an integrated whole, and that the EPA’s administration of that provision should reflect a reasoned consideration of all relevant factors that is not artificially

severed into distinct findings and rulemakings across time.

In addition, we propose that even if intervening legal developments have not foreclosed the regulation of GHG emissions from new motor vehicles and engines under CAA section 202(a), they provide a reasonable basis for the Administrator to approach the inquiry with greater caution today than was applied in the Endangerment Finding. At a minimum, *Loper Bright* confirms that the EPA can no longer rely on statutory silence or ambiguity to imply authorities and discretion not expressly conferred by statute. In exercising the judgment required by CAA section 202(a), the Administrator would choose to adhere as closely as possible to the statutory language, prior Agency implementation of that language, and the initial approach set out in the 2008 ANPRM. We propose that the Administrator’s new approach requires rescinding the Endangerment Finding as fundamentally inconsistent with the framework set out in this proposed alternative.

Moreover, we propose that the Administrator would not now find, in light of the ongoing uncertainties in relevant scientific data and analyses bearing on the question, that the evidence is sufficiently reliable to determine that GHG emissions from new motor vehicles and engines meet the standard for regulation in CAA section 202(a). As discussed in the preamble, the Administrator reviewed the scientific record as part of the reconsideration process and no longer has the degree of confidence previously expressed in the analyses relied upon in the Endangerment Finding, the attribution decisions made in the Endangerment Finding, and the balance of projected adverse impacts and beneficial impacts of climate change struck in the Endangerment Finding.

The EPA seeks comment, for the first time since the 2009 Endangerment Finding was proposed, on whether, due to new scientific information and developments since the 2009 Endangerment Finding, there is a strong enough scientific record to support an affirmative finding that GHG emissions from section 202(a) sources cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare. Prompt action is needed to address these concerns, and the Administrator looks forward to stakeholder input on the continuing vitality of the assumptions, predictions, and conclusions animating the 2009 Endangerment Finding.

Additionally, the EPA seeks comment on, if the EPA were to make such a

finding, whether a new comment period would be required and what information would be necessary to provide such a finding. To aid in the EPA's decision making, we also seek comment on the breadth of the Administrator's discretion to exercise judgment by rejecting the approach taken in the Endangerment Finding and the results of adopting a different approach. We also seek comment on any additional aspects of the Endangerment Finding that may have fallen short of the administrative law requirement that agency action be reasonable and reasonably explained. Conversely, we seek comment on why the approach taken in the Endangerment Finding remains reasonable given the legal and scientific developments discussed in this proposal, and the impact, if any, of the EPA's denial of rulemaking petitions in 2022 and 2010 on this alternative proposal. As previously noted, we are also seeking comment on whether the denials in 2022 and 2010 were unlawful for any additional reasons not explored explicitly in this proposal.

V. Separate Bases for Proposed Repeal of GHG Emission Standards

In this section, the EPA proposes repealing existing GHG emission standards for reasons unrelated to the decision to rescind or retain the Endangerment Finding. CAA section 202(a) requires us to consider additional factors before emission standards issued in response to an endangerment finding may go into effect, including cost, the useful life of the vehicles or engines, and the availability of "requisite technology."⁹⁸ Consistent with the language and structure of the statute and the Supreme Court's express reservation of this question in *Massachusetts*, we propose to conclude that policy considerations may be taken into account, at a minimum, when setting standards in response to an endangerment finding or, as here, when determining whether to maintain standards already established.⁹⁹

Specifically, we are proposing that there is no "requisite technology" for emission control for light- and medium-duty vehicles because reducing GHG emissions from such vehicles to zero would not measurably impact GHG concentrations in the atmosphere or the rate of global climate change. Relatedly, we are proposing that there is no "requisite technology" for emission

control for heavy-duty vehicles and engines, even if considered in combination with light- and medium-duty vehicle standards. Finally, we are proposing that GHG emission standards may harm, rather than advance, public welfare as defined in the CAA by reducing fleet turnover that improves air quality, safety, consumer choice, and economic opportunity.

Each of these proposals would, if finalized, serve as an independent and sufficient basis for repealing the relevant GHG emission standards as proposed in section VI of this preamble. The EPA seeks comment on all aspects of these alternative proposed bases for repeal of the GHG emission standards as indicated in the remainder of this section.

A. There Is No Requisite Technology for Light- and Medium-Duty Vehicles That Meaningfully Addresses the Identified Dangers of the Six "Well-Mixed" GHGs

The EPA proposes to repeal GHG emission standards for light- and medium-duty vehicles because no technology for this source category is capable of preventing or controlling the "air pollution" identified as a danger to public health and welfare in the Endangerment Finding, *i.e.*, global concentrations of GHGs in the upper atmosphere. CAA section 202(a)(1) provides that new motor vehicles and engines may comply with emission standards "as complete systems" or by "incorporat[ing] devices to prevent or control" the air pollution that endangers public health or welfare.¹⁰⁰ CAA section 202(a)(2) further provides that emission standards cannot go into effect until "after such period as the Administrator finds necessary to permit the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such period."¹⁰¹

As noted elsewhere in this preamble, GHG emissions from the United States were 11 percent of global GHG emissions in 2022,¹⁰² down from 23.5 percent in 2005.¹⁰³ The U.S. transportation sector accounted for 28 percent of domestic GHG emissions in 2022, and light- and medium-duty vehicles accounted for 57 percent of U.S. transportation sector GHG emissions.¹⁰⁴ Taken together, the best

available data indicate that GHG emissions from light- and medium-duty vehicles in the United States amounted to approximately 1.8 percent of global GHG emissions in 2022. Reducing GHG emissions from light- and medium-duty vehicles in the United States to zero would result in a 1.8 percent decrease in global GHG emissions, which corresponds to an approximate 3 percent reduction in predicted warming trends (2025 CWG Draft Report at 130).¹⁰⁵ To note, these percentages do not account for trends demonstrating that the United States has been decreasing absolute GHG emissions while other countries like China are significantly increasing their GHG emissions.¹⁰⁶

Global warming trends from 1979 to 2023, the period with the best available data, were determined to a precision (or margin of error) of plus or minus 15 percent total (*id.*). An estimated 3 percent reduction in global warming trends is well below the scientific threshold for measurability and is not a reliable measure for regulatory purposes.

By defining global GHG concentrations in the upper atmosphere as the relevant threat to public health and welfare in the United States, the Endangerment Finding identified a problem that the regulatory tools Congress provided under CAA section 202(a) are simply unable to meaningfully address. Notably, that action defined the relevant "air pollution" as six "well-mixed" GHGs, meaning the combination of GHGs rather than an individual air pollutant that could be emitted by certain sources at greater or lesser levels and would be more amenable to effective prevention and control. 74 FR 66537. To qualify as a "requisite technology" with any measurable impact on the identified danger, an engine design or device would need to *remove* GHGs already present in the atmosphere and would no longer qualify as an *emission* standard for the new motor vehicle or motor vehicle engine.

Additionally, the "requisite technology" to meet the identified danger would, at minimum, require a complete change from internal

Gas Emissions and Sinks: <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.

¹⁰⁵ See also U.S. Transportation Sector Greenhouse Gas Emissions 1990–2022. (2024). United States Environmental Protection Agency 89 FR 11275 (Feb. 14, 2024); Statistical Review of World Energy. (2024). Energy Institute: <https://www.energyinst.org/statistical-review>.

¹⁰⁶ Crippa, M. et al. (2023). GHG emissions of all world countries. Publications Office of the European Union: <https://doi.org/10.2760/953322>.

¹⁰⁰ 42 U.S.C. 7521(a)(1).

¹⁰¹ 42 U.S.C. 7521(a)(2).

¹⁰² U.S. Environmental Protection Agency. (Last updated Mar. 31, 2025). Global Greenhouse Gas Overview: <https://www.epa.gov/ghgemissions/global-greenhouse-gas-overview>.

¹⁰³ 74 FR 66539.

¹⁰⁴ U.S. Environmental Protection Agency. (Last updated July 1, 2025). Inventory of U.S. Greenhouse

⁹⁸ See 42 U.S.C. 7521(a)(1)–(2), (a)(3)(B).

⁹⁹ See *Massachusetts*, 549 U.S. at 534–35 ("We need not and do not reach the question whether on remand EPA must make an endangerment finding, or whether policy concerns can inform EPA's actions in the event that it makes such a finding.").

combustion engines to EVs or another zero-emissions technology. We propose that this form of fuel switching is analogous to the generation-shifting approach we attempted to take for existing stationary sources and that was held to be illegal in *West Virginia*. As explained further below, even a complete shift toward EVs or other zero-emission vehicle and engine technologies in the United States would not reliably and meaningfully reduce elevated global concentrations of GHGs and, therefore, not reliably and meaningfully reduce the risks of climate change asserted in the Endangerment Finding. Given the relatively low share of total global anthropogenic emissions, new motor vehicles and engines in the United States would need to remove GHGs from the atmosphere to have the potential for a reliable impact on GHG concentrations and potential impacts, particularly when viewed in light of increased growth in foreign emissions sources.

The EPA seeks comment on this proposed rationale, including on the proper interpretation of “requisite technology,” the appropriate standard for measuring pollution prevention and control, and the scientific threshold for determining measurable impacts on trends in climate change.

B. There Is No Requisite Technology for Heavy-Duty Vehicles That Addresses the Identified Dangers of the Six “Well-Mixed” GHGs

For similar reasons, the EPA also proposes to repeal GHG emission standards for heavy-duty vehicles because there is no requisite technology capable of preventing or controlling the “air pollution” identified in the Endangerment Finding. Heavy-duty vehicles account for an even lower percentage of GHG emissions in the U.S. transportation sector than light- and medium-duty vehicles: 23 percent, as compared to 57 percent.¹⁰⁷ Therefore, of the global GHG emissions in 2022, heavy-duty vehicles contributed approximately 0.7 percent. If all heavy-duty vehicles in the U.S. no longer emitted GHGs, that would only result in a decrease of 0.7 percent of all worldwide GHG emissions. As noted in the previous subsection, that low figure corresponds to a predicted warming impact well below the measurability threshold because warming trends are determined at a precision of plus or

minus 15 percent (2025 CWG Draft Report at 130).

The EPA establishes light- and medium-duty vehicle and heavy-duty vehicles separately under distinct grants of authority in CAA section 202(a) and must justify actions taken with respect to each source category separately. We note, however, that even when considered together, the impact of reducing all GHG emissions from motor vehicles and motor vehicle engines to zero would not result in a measurable impact on trends in climate change. A combined 2.5 percent reduction in global GHG emissions would not result in a more than *de minimis* impact on trends in climate change and would not demonstrate a requisite technology for regulatory purposes.

C. Eliminating GHG Emissions From All Motor Vehicles Would Be Futile

The EPA is proposing that the Agency must consider the impacts of making an Endangerment Finding and cannot arbitrarily separate parts of a sentence within different regulations. Here, we propose that this interpretation means the Agency should not and need not make an endangerment finding under CAA section 202(a)(1) when the regulatory authority conferred by that provision would have no meaningful impact on the identified dangers. As discussed in subparts A and B of this section, we propose that there is no requisite technology that would result in meaningful changes to the impacts of climate change. Whereas the determination in subparts A and B was based on the statutory language within CAA section 202(a)(2), this subpart is based on the statutory language in CAA section 202(a)(1).

Specifically, we propose that when considering whether to make an endangerment finding, the Administrator should consider the ability of the EPA’s CAA section 202(a)(1) authority to meaningfully address the identified risks. As noted above, the Endangerment Finding itself recognized that the relative contribution of GHG emissions to global concentrations from new motor vehicles and engines in the United States is small, and recent data and analyses demonstrate that the share has significantly decreased since 2009. Under the circumstances, even a complete elimination of all GHG emissions from new motor vehicles and engines would not address the risks attributed to elevated global concentrations of GHGs. We propose that this futility further demonstrates that CAA section 202(a) does not, as a matter of text and structure, authorize or

require the EPA to prescribe emission standards for GHG emissions from new motor vehicles and engines. We further propose that it was improper for the Agency to attempt to get around this problem in the Endangerment Finding by asserting that parties regulated under CAA section 202(a) must “do their part” when, in reality, only dramatic reduction in foreign emissions, as well as reductions from domestic sources regulated under other provisions of the CAA, would have any meaningful impact on the global climate change concerns asserted in the Endangerment Finding. The CAA does not authorize the EPA to regulate international sources of emissions, and the statute provides distinct regulatory authority, subject to distinct requirements and standards, for other domestic sources.

D. More Expensive New Vehicles Prevent Americans From Purchasing New Vehicles That Are More Efficient, Safer, and Emit Fewer GHGs

The EPA also proposes to repeal GHG emission regulations for new motor vehicle and motor vehicle engines because the resulting increase in price disincentivizes consumers from purchasing new vehicles and keeps less efficient vehicles on the road for longer.¹⁰⁸ Complying with our GHG emission standards often requires manufacturers to design and install new and more expensive technologies, thereby increasing the price of new vehicles and reducing consumer demand. More expensive new vehicles are cost prohibitive for some consumers, and those consumers are likely to turn to the used vehicle market or continue using an older vehicle.¹⁰⁹

With respect to commercial vehicles, it is widely understood that many commercial vehicle owners and commercial fleet operators consider the total cost of ownership in determining when to purchase new commercial vehicles. The total cost of ownership involves many factors, including, for example, not only vehicle price, but also owning and operating costs (e.g., service and maintenance costs and fuel costs). Depending on the impacts of the GHG regulations on the specific vehicle category and the considerations relevant to the commercial vehicle purchaser, the impacts of GHG regulations may result in a decrease in new commercial vehicle sales. We also note that commercial vehicle owners and fleet operators may incur additional costs

¹⁰⁷ U.S. Environmental Protection Agency. (Last updated July 1, 2025). Inventory of U.S. Greenhouse Gas Emissions and Sinks: <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>.

¹⁰⁸ For additional discussion on this topic, see 85 FR 24174 (Apr. 30, 2020).

¹⁰⁹ A discussion of the impact of higher vehicle prices on slowing fleet turnover can be found at 85 FR 24626 (Apr. 30, 2020).

associated with ongoing compliance obligations under the GHG standards for an applicable model year, including testing and reporting requirements that are reflected in the total cost of ownership but not necessarily the vehicle price.¹¹⁰

All other things being equal, an increase in the price of new vehicles can result in consumers keeping their vehicles for longer periods, delaying the purchase of new vehicles, and decreasing fleet turnover. Contrary to the goals of the EPA's GHG emission standards and the intended purpose of CAA section 202(a), a delay in fleet turnover can negatively impact air quality because older vehicles tend to emit higher levels of air pollutants, including criteria pollutants and hazardous air pollutants, regulated by the EPA.¹¹¹ Slowing fleet turnover is of particular concern with respect to the EPA's 2024 vehicle GHG rules because of the large increase in vehicle technology costs which will likely lead to large increases in purchase prices, and the impact battery electric and fuel cell vehicle technologies will have on purchasing decisions of consumers (for light-, medium-, and heavy-duty vehicle buyers). Increased prices and some consumers rejecting battery electric and fuel cell vehicle technologies may lead consumers to hold on to their existing vehicles longer. Vehicles are more likely to emit less air pollution with each subsequent model year because of improvements in technology, ordinary wear and tear that decreases the effectiveness of installed technology, and greater stringency in more recent regulations for criteria pollutants and hazardous air pollutants.

For these reasons, the EPA has serious concerns that its GHG standards may be harming air quality by raising prices and reducing fleet turnover. We seek comment on this proposed basis for repeal, including on the economics of fleet turnover, the relative efficiency and emission reductions achieved by newer vehicles, modeling of the changes vehicle criteria pollutant and air toxic emissions as well as changes in upstream emissions, modeling of potential changes in air quality (including ozone and particulate matter) and the potential costs to air quality of retaining standards that may slow fleet turnover as compared to the potential

benefits of retaining GHG emission standards in response to global climate change concerns.

In addition, the EPA notes that greater availability of new vehicles at lower prices furthers public welfare by promoting vehicle safety and consumer choice. New vehicles must meet all Federal Motor Vehicle Safety Standards (FMVSS), which NHTSA continually updates over time to respond to new concerns and to incorporate improvements in safety technology. Manufacturers install technologies to meet these safety requirements and may also include newer safety features not required by regulation. NHTSA has found that newer vehicles offer improved safety features and designs, leading to reduced fatalities and injuries in crashes relative to older vehicles.¹¹² A delay in the turnover of the fleet also could lead to a higher risk to drivers and passengers and delay the safety benefits provided by new vehicles, thereby harming the public welfare in a more direct way than the global climate change impacts animating the EPA's GHG standards.

Moreover, the EPA notes that the ability to own a vehicle is an important means to unlock economic freedom and participate in society as an employee, consumer, and community member. Transportation mobility is essential to economic and social mobility, and there are no readily available substitutes for passenger vehicles in many urban and virtually all non-urban communities throughout the United States. By increasing the price of new vehicles and existing vehicles subject to the standards at manufacture, our GHG emission standards may prevent some people from accessing the benefits of vehicle ownership. For example, in EPA's 2024 vehicle GHG rules, the EPA projected significant increases in vehicle technology costs which we estimated would be passed on to consumers as price increases.¹¹³ In addition, the 2025 OBBB ended the IRA's 30D new clean vehicle tax credit before the end of 2025 (while the IRA allowed for this tax credit through

2032). This significant change will increase the effective price of many new battery electric, plug-in hybrid electric, and fuel cell vehicles, including leased vehicles.

The EPA seeks comment on these additional rationales, including on whether such public welfare considerations can and should be considered when prescribing and revising emission standards under CAA section 202(a). As noted earlier in this preamble, Congress defined "effects on welfare" broadly in CAA section 302(h) to include, but not be limited to, "hazards to transportation, as well as effects on economic values and on personal comfort and well-being." 42 U.S.C. 7602(h). We seek comment on how to give effect to this statutory language as incorporated into the reference in CAA section 202(a) to effects on "public health or welfare." We further seek comment as a general matter on whether the Endangerment Finding and resulting regulations have resulted in disbenefits, that is, on any public health and welfare harms that may flow from the Endangerment Finding and resulting regulations themselves.

VI. Proposed Repeal of GHG Emission Standards

Consistent with the proposed rescission of the Endangerment Finding in section IV.A and IV.B of this preamble, the additional considerations in section V of this preamble, and the discussion of legal authority in section III of this preamble, the EPA is proposing to repeal all GHG emission standards for light-duty vehicles, medium-duty vehicles, heavy-duty vehicles, and heavy-duty engines. This includes emission standards for the subset of four of the six "well-mixed GHGs" whose elevated concentrations in the upper atmosphere the 2009 endangerment finding identified as the "air pollution" in question that are actually emitted by such vehicles and engines—CO₂, N₂O, methane, and HFCs—as well as the compliance provisions for the GHG standards. These proposed changes would apply to all MYs of vehicles and engines, including MYs that have completed manufacture prior to the effective date of any final rule.

Under the proposed revisions, manufacturers may in some cases already be changing their production processes to apply updated emission control information labels for vehicles and engines. Manufacturers may also already be revising warranty statements provided with their engines and vehicles. We also note that this

¹¹⁰ See section VI.C of this preamble for a discussion of the heavy-duty vehicle and engine GHG regulatory requirements and compliance obligations.

¹¹¹ A discussion of the impact of higher vehicle prices on slowing fleet turnover and thus increasing emissions can be found at 85 FR 24186 and 25039 (Apr. 30, 2020).

¹¹² U.S. Department of Transportation, National Highway Traffic Safety Administration. How Vehicle Safety Has Improved Over the Decades: <https://www.nhtsa.gov/how-vehicle-safety-has-improved-over-decades>.

¹¹³ For a discussion of this topic, see chapter 4.2 of the Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Buty and Medium-Duty Vehicles final rule RIA, <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockkey=P1019VPM.pdf>, and Chapter 3 of the Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles: Phase 3 final rule RIA, <https://nepis.epa.gov/Exe/ZyPDF.cgi/P101ABVT.PDF?Dockkey=P101ABVT.PDF>.

proposed action would not, if finalized, require manufacturers to adapt immediately if doing so would raise timing concerns. Unlike the GHG emission standards we propose to repeal, this proposed action would increase flexibility and not mandate any particular technology response. Manufacturers will have no vehicle technology mix constraints which arise from the EPA GHG standards and will be free to produce a range of technologies, including gasoline, diesel, alternative fuels, and plug-in electric vehicles. Furthermore, we have adequate statutory authority to approve manufacturers' requests to continue to offer a warranty that is more generous than required under regulations, and to include information on emission control information labels that is more than required under the proposed regulations. Thus, we do not anticipate material compliance difficulties on the part of manufacturers if this repeal action is finalized as proposed.

In section VI.A of this preamble, we discuss the anticipated impacts of the proposed repeal of GHG emission standards under CAA section 202(a) on the overall regulatory scheme for parties currently subject to the standards. As explained in this section and elsewhere in this preamble, we are not proposing to reopen or substantively revise any emission standards for criteria pollutants or hazardous air pollutants or to reopen or substantively revise any regulatory provisions related to NHTSA's CAFE standards or the EPA's role in administering EPCA and EISA. Moreover, this proposed action would not impact Federal preemption for motor vehicle and engine emission standards under CAA section 209(a) or under EPCA and EISA, including with respect to GHGs.

In section VI.B of this preamble, we describe the light-duty (LD) and medium-duty (MD) vehicle program and the proposed changes to the GHG regulations for that program. In section VI.C of this preamble, we describe the heavy-duty (HD) engine and vehicle program and proposed regulatory changes. We request comment on all proposed changes described in this section, including on any additional regulatory provisions for engines and vehicles that should be removed as part of repealing the GHG standards or should be retained to effectuate unrelated standards that we are not proposing to repeal or revise. To aid in public participation, we have submitted a memorandum to the docket that

includes redline text highlighting all proposed changes to the regulations.¹¹⁴

The EPA's engine and vehicle programs are codified in Title 40 of the CFR. Specifically, the standard-setting parts for light- and medium-duty vehicles are located in 40 CFR part 85 and 86. The standard-setting part for heavy-duty engines is located in 40 CFR part 1036 and the standard-setting part for heavy-duty vehicles is 40 CFR part 1037. Each standard-setting part includes regulations describing emission standards and related requirements and compliance provisions for certifying engines or vehicles. As explained in this section and elsewhere in this preamble, the EPA is proposing to retain measurement procedures, reporting requirements, and credit provisions for the light-duty program necessary for demonstrating compliance with NHTSA's CAFE standards and fuel economy labeling to meet our statutory obligations under EPCA and EISA. We consider any changes to those requirements as outside the scope of this rulemaking and may consider changes to these provisions, as appropriate, in a future rulemaking. Further, as explained in this section and elsewhere in this preamble, we are not proposing to reopen or substantively revise emission standards or compliance provisions related to criteria pollutant exhaust emissions (*i.e.*, oxides of nitrogen (NO_x), hydrocarbons (HC), particulate matter (PM), and carbon monoxide (CO)), air toxic emissions, or evaporative and refueling emissions.¹¹⁵ We may consider those issues, as appropriate, in future rulemakings.

A. Scope and Impacts of Proposed Repeal

The EPA is proposing to repeal all regulatory provisions relating to our GHG emission programs for light- and medium-duty vehicles and heavy-duty vehicles and engines on the bases set forth in sections III.A, III.B, and IV of this preamble. If finalized, any one of these alternative proposals would provide a sufficient basis for repealing our existing GHG regulations for new motor vehicles and new motor vehicle engines. Finalizing the proposed rescission of the Endangerment Finding as set out in section IV.A would provide

sufficient basis for repeal because the EPA would lack statutory authority to regulate emissions based on global climate change concerns under CAA section 202(a). Finalizing the proposed rescission of the Endangerment Finding as set out in section IV.B would provide sufficient basis for repeal because the Administrator would conclude that the scientific evidence of endangerment and contribution is too uncertain to satisfy the standard for regulation under CAA section 202(a). And finalizing the proposed rationales set out in section V would provide sufficient basis for repeal, separately or in combination, because the EPA would conclude that our GHG emission standards do not further public health and welfare and cannot go into effect.

The repeal proposed in this NPRM is limited to the regulatory provisions for GHG emission standards found in 40 CFR parts 85, 86, 1036, and 1037, with minor conforming adjustments to unrelated emission standards for new motor vehicles and engines in 40 CFR parts 600 and 1039. As detailed in subparts B and C of this section, this NPRM is not proposing to revise emission standards for criteria pollutants or air toxics. The EPA may reconsider and propose to revise the regulatory provisions for those programs in a separate rulemaking action. Similarly, this NPRM is not reopening or proposing to revise regulatory provisions necessary for NHTSA's CAFE standards or the EPA's co-administration of EPCA and EISA. Accordingly, we are not seeking public comment on the substance of these distinct regulatory programs and will consider such comments outside the scope of this rulemaking.

For this reason, the proposed repeal would not impact Federal preemption under EPCA, as amended by EISA, related to fuel economy standards. EPCA provides that when "an average fuel economy standard prescribed under this chapter is in effect, a State or a political subdivision of a State may not adopt or enforce a law or regulation related to fuel economy standards or average fuel economy standards for automobiles covered by an average fuel economy standard under this chapter"¹¹⁶ unless the standards are identical or apply only to vehicles obtained for the use of the State or political subdivision.¹¹⁷ If finalized, this action would not reopen or revise any fuel economy standards or alter the EPA's statutory role in co-administering

¹¹⁴ Memorandum to Docket EPA-HQ-OAR-2025-0194, "Redline Version of EPA's Proposed Regulations for the Reconsideration of 2009 Endangerment Finding and Greenhouse Gas Vehicle Standards." August 2025.

¹¹⁵ In this proposed rulemaking, NO_x, HC, PM, and CO are sometimes described collectively as "criteria pollutants" because they are either criteria pollutants under the CAA or precursors to the criteria pollutants ozone (O₃) and PM.

¹¹⁶ 49 U.S.C. 32919(a).

¹¹⁷ 49 U.S.C. 32919(b)–(c).

any such standards, including NHTSA's CAFE standards.

The proposed repeal also would not impact Federal preemption of emission standards for new motor vehicle and engine emission standards. CAA section 209(a) provides that “[n]o State or any political subdivision thereof shall adopt or attempt to enforce any standard relating to the control of emissions from new motor vehicles or new motor vehicle engines subject to this part,” including “certification,” “inspection” or “approval” requirements “relating to the control of emissions from” such vehicles or engines.¹¹⁸ Because new motor vehicles and engines currently subject to GHG emission standards would remain subject to Title II of the CAA, the statute would continue to preempt “any” State or local “standard relating to the control of emissions.” Relatedly, the CAA would continue to preempt Federal common-law claims for GHG emissions because “Congress delegated to EPA the decision whether and how to regulate” such emissions. *Am. Elec. Power Co. v. Connecticut*, 564 U.S. 410, 426 (2011). We would retain our authority to prescribe emission standards for any air pollutant that, in the Administrator’s judgment, causes or contributes to air pollution that may reasonably be anticipated to endanger public health or welfare. The bases for repeal proposed in this action would not foreclose us from regulating CO₂, methane, NO_x, HFCs, PFCs, or SF₆ emissions from new motor vehicles or engines if the Administrator determines that one or more of those gases meet the requirements for regulation under CAA section 202(a), as discussed herein. As noted above, we seek comment on the continued preemptive effect of the CAA in the event that the EPA finalizes the proposed rescission or otherwise concludes that it lacks authority to regulate GHG emissions under CAA section 202(a) or any other specific regulatory provision of the CAA.

The EPA’s engine and vehicle programs are codified in Title 40 of the CFR. Specifically, the standard-setting parts for light- and medium-duty vehicles are located in 40 CFR parts 85 and 86. The standard-setting part for heavy-duty engines is located in 40 CFR part 1036 and the standard-setting part for heavy-duty vehicles is 40 CFR part 1037. Each standard-setting part includes regulations describing emission standards and related requirements and compliance provisions for certifying engines or vehicles.

B. Light- and Medium-Duty Vehicle GHG Program

This subpart provides background on the EPA’s light-duty and medium-duty vehicle GHG emission programs. In general, through a series of rulemakings beginning with Model Year 2010 for light-duty vehicles and Model Year 2014 for medium-duty vehicles, the EPA increased the stringency of the GHG standards for these vehicles over time, in particular the CO₂ standard. Section VI.A.2 of this preamble describes the proposed changes to the light-duty and medium-duty vehicle GHG regulations.

1. Background on the Light- and Medium-Duty Vehicle GHG Program

In 2010, the EPA relied on the Endangerment Finding to adopt the first GHG emission standards for passenger cars and light trucks for MYs 2012 through 2016 in a joint rulemaking with NHTSA.¹¹⁹ In 2012, the EPA and NHTSA adopted another set of GHG standards (issued by EPA) and fuel economy standards (issued by NHTSA) for passenger cars and light trucks for MYs 2017 and later in a joint rulemaking.¹²⁰ In 2020, the EPA and NHTSA revised the standards that had previously been adopted and extended them for MYs 2021 through 2026.¹²¹ In 2021, we further revised GHG standards for passenger cars and light trucks for MYs 2023 through 2026.¹²² For medium-duty vehicles, we initially adopted GHG standards as part of the Phase 1 and Phase 2 heavy-duty GHG standards, as described in section VI.B.1 of this preamble. In 2024, we adopted new standards for passenger cars, light trucks, and medium-duty vehicles starting in MY 2027, effectively combining standards that had previously been maintained separately.¹²³

The EPA has also taken various actions to comply with statutory obligations under EPCA and EISA. Enacted in 1975, EPCA requires NHTSA to establish a regulatory program for motor vehicle fuel economy (now known as CAFE standards) and requires the EPA to establish measurement procedures, data collection procedures, and rules for calculating average fuel economy values in support of NHTSA’s CAFE standards. In 2007, Congress amended EPCA by enacting EISA, which required continuing increases in the stringency of CAFE standards for passenger cars and light trucks through

MY 2020. EISA also authorized new fuel consumption standards for medium-duty vehicles and heavy-duty engines and vehicles.¹²⁴ Those standards, and the EPA’s heavy-duty engine and vehicle GHG programs, are detailed in section VI.B of this preamble.

To comply with EPCA and EISA, the EPA has adopted regulations for fuel economy measurements, calculations, and reporting under 40 CFR part 600. The regulation at 40 CFR part 600 now includes additional provisions for measuring, calculating, and reporting fuel consumption values for medium-duty vehicles. This regulatory structure was designed to maximize efficiency within the Federal government and minimize the burden on the engine and vehicle manufacturers by centralizing data submission. We share information with NHTSA as needed to support implementation of NHTSA’s fuel economy and consumption standards.

2. Proposed Changes to the Light- and Medium-Duty Vehicle GHG Regulations

The EPA’s light-duty and medium-duty vehicle emission regulations are spread across three CFR parts. 40 CFR part 85 includes various general compliance provisions for both criteria pollutant and GHG emissions. Many of those provisions apply equally to highway motorcycles. 40 CFR part 86 includes emission standards and certification provisions for both criteria pollutant and GHG emissions. 40 CFR part 600 includes measurement and reporting procedures related to fuel economy and GHG standards and to fuel economy labeling.

In the following subsections, we describe our proposed removal and amendment of specific portions of each of these regulatory parts. In general, the approach taken in this proposal is to remove the MY 2012 and later GHG emission standards for passenger cars and light trucks and the MY 2014 and later GHG emission standards for medium-duty vehicles. We also propose to remove the testing and reporting requirements associated with the GHG emission standards. In keeping with our obligations under EPCA, as noted in section VI.A.1 of this preamble, we are not proposing to remove the testing and reporting requirements related to CAFE standards for passenger cars and light trucks and are not reopening those requirements. We request comment on the proposed regulatory changes and whether additional changes should be considered.

¹¹⁹ 75 FR 25324 (May 7, 2010).

¹²⁰ 77 FR 62624 (Oct. 15, 2012).

¹²¹ 85 FR 24174 (Apr. 30, 2020).

¹²² 86 FR 74434 (Dec. 30, 2021).

¹²³ 89 FR 27842 (Apr. 18, 2024).

¹²⁴ 49 U.S.C. 32902(k).

¹¹⁸ 42 U.S.C. 7543(a).

a. 40 CFR Part 85—Compliance Provisions for Light- and Medium-Duty Vehicles

In general, we propose to amend 40 CFR part 85 to remove all references to

GHG emission standards and related provisions while retaining provisions that support our criteria pollutant emission program. In this subsection, we describe several proposed amendments that are necessary to

remove GHG-related provisions from 40 CFR part 85 while ensuring that criteria pollutant emission standards are not substantively impacted. Table 1 provides a summary of the proposed amendments to 40 CFR part 85.

TABLE 1—SUMMARY OF PROPOSED CHANGES TO LIGHT-DUTY AND MEDIUM-DUTY HIGHWAY ENGINE REGULATIONS UNDER 40 CFR PART 85

40 CFR part 85	Sections proposed to amend
Subpart F—Exemption of Clean Alternative Fuel Conversions From Tampering Prohibition	85.525.
Subpart P—Importation of Motor Vehicles and Motor Vehicle Engines	85.1515.
Subpart S—Recall Regulations	85.1803, 85.1805.
Subpart T—Emission Defect Reporting Requirements	85.1902.
Subpart V—Warranty Regulations and Voluntary Aftermarket Part Certification Program	85.2103.

The regulations at 40 CFR part 85, subpart F, provide an exemption from the general tampering prohibition for clean alternative fuel conversions. Specifically, the regulations describe how anyone modifying an in-use vehicle to run a different fuel can demonstrate that the fuel conversion maintains a level of emission control that qualifies them for an exemption from the tampering prohibition. This exemption generally allows for the modifying of vehicles already certified to emission standards in a way that does not cause the modified vehicle to exceed the emission standards that apply for the certified vehicle. The demonstration applies for both criteria and GHG emissions. We are proposing to revise 40 CFR 85.525 by removing the requirement to demonstrate compliance with GHG emissions. Program requirements related to criteria exhaust, evaporative, and refueling emissions and onboard diagnostics would remain unchanged.

The regulation at 40 CFR 85.1515 describes the standards that apply for Independent Commercial Importers in their practice of importing used vehicles. We are proposing only to remove text disallowing generation and use of GHG emission credits. We note

further that the regulation requires Independent Commercial Importers to meet all the standards that apply under 40 CFR part 86. With the proposed changes described in this action, the removal of GHG standards from 40 CFR part 86, subpart S, would apply equally to imported vehicles. Imported vehicles would continue to be subject to criteria exhaust, evaporative, and refueling emission standards and requirements for onboard diagnostics as specified in 40 CFR part 86, subpart S.

We are proposing to revise the recall-related instructions for remedial plans and consumer notification in 40 CFR 85.1803 and 85.1805 to remove a reference to 40 CFR 86.1865(j)(3), which we are proposing to remove in this action. The referenced paragraph relates to recall provisions for vehicles that do not comply with GHG standards. We are also proposing to revise definitions of “Emission-related defect” and “Voluntary emissions recall” in 40 CFR 85.1902 where those definitions describe how manufacturers must report GHG-related defects differently than defects related to criteria pollutant emission standards. Finally, we are proposing to amend the warranty provisions for specified major emission control components in 40 CFR 85.2103

by removing the reference to batteries serving as a Renewable Energy Storage System for electric vehicles and plug-in hybrid electric vehicles, along with all components needed to charge the system, store energy, and transmit power to move the vehicle. We would continue to apply the basic emission-related warranty requirement for a period of two years or 24,000 miles where such batteries qualify as an emission-related component.

b. 40 CFR Part 86—Emission Standards and Certification Requirements for Light- and Medium-Duty Vehicles

In general, we propose to amend 40 CFR part 86 to remove all GHG emission standards, references to such standards, and related provisions while retaining provisions that support our criteria pollutant emission program. In this subsection, we describe several proposed amendments that are necessary to remove GHG-related provisions from 40 CFR part 86 while ensuring that criteria pollutant emission standards are not substantively impacted. Table 2 provides a summary of the regulations we propose either to remove or to amend in 40 CFR part 86.

TABLE 2—SUMMARY OF PROPOSED CHANGES TO LIGHT-DUTY AND MEDIUM-DUTY HIGHWAY ENGINE REGULATIONS UNDER 40 CFR PART 86

40 CFR part 86	Sections proposed to remove	Sections proposed to amend
Subpart S—General Compliance Provisions for Control of Air Pollution From New and In-Use Light-Duty Vehicles, Light-Duty Trucks, and Heavy-Duty Vehicles.	86.1815–27, 86.1818–12, 86.1819–14, 86.1865–12, 86.1866–12, 86.1867–12, 86.1870–12.	86.1. 86.1801–12, 86.1803–01, 86.1805–12, 86.1805–17, 86.1807–01, 86.1809–12, 86.1810–09, 86.1810–17, 86.1811–17, 86.1811–27, 86.1816–18, 86.1822–01, 86.1823–08, 86.1827–01, 86.1828–01, 86.1829–15, 86.1830–01, 86.1835–01, 86.1838–01, 86.1839–01, 86.1841–01, 86.1844–01, 86.1845–04, 86.1846–01, 86.1848–10, 86.1854–12, 86.1861–17, 86.1868–12, 86.1869–12.

We are proposing to amend the list of reference documents in 40 CFR 86.1 by removing documents that are referenced only in regulations that we are proposing to remove.

We are proposing to amend the applicability statements in 40 CFR 86.1801–12 by removing references to GHG standards and related compliance provisions. We are also proposing to remove the instruction related to work factor for vehicles above 14,000 pounds gross vehicle weight rating (GVWR) at 40 CFR 86.1801–12(a)(3) since that is meaningful only in the context of GHG standards. We adopted the work-factor provision in a 2016 final rule as a means of limiting the extent to which manufacturers would certify those larger heavy-duty vehicles in test groups along with chassis-certified medium-duty vehicles.¹²⁵ Removing the instruction to calculate GHG standards based on a work factor appropriate for medium-duty vehicles, without other compensating changes, could lead to a greater number of heavy-duty vehicles certified as medium-duty vehicles. The work-factor provision was adopted as a means of addressing competing concerns from different manufacturers. As a result, we are proposing to limit the use of this provision to heavy-duty vehicles with a maximum value of 19,500 pounds GVWR. We believe this limitation is the best way to maintain a consistent approach for certifying affected vehicles.

We are proposing to amend the definitions in 40 CFR 86.1803–01 by removing several defined terms that are used only in regulatory provisions that we are proposing to remove. This includes proposing to remove the definition of “configuration”; while this definition is no longer needed, we are proposing to retain the slightly different definition of “vehicle configuration,” since that definition is needed to support standards related to criteria pollutants. We are accordingly proposing to amend several references across 40 CFR part 86, subpart S, to change from a generic reference to “configuration” and replace it with the specific reference to “vehicle configuration.” We are also proposing to amend 40 CFR 86.1803–01 by adding a definition for “work factor” that is consistent with the definition that is embedded in 40 CFR 86.1819–14. We adopted the definition of “work factor” in 40 CFR 86.1819–14 primarily as a means of accounting for specific vehicle characteristics in establishing GHG emission standards for medium-duty vehicles. We are proposing to remove all

of 40 CFR 86.1819–14 as described below. However, we are keeping the definition of work factor to support the definition of “medium-duty passenger vehicle,” which relies on the work factor concept to categorize vehicles for applying criteria pollutant emission standards.

We are proposing to amend 40 CFR 86.1803–01 and 86.1809–12 by removing references to the air conditioning efficiency test as part of the consideration for determining what is a defeat device. We are proposing to eliminate the air conditioning efficiency test from the EPA certification program because it was only used to generate GHG credits. Note that we are not proposing in this NPRM to remove the air conditioning efficiency credit provisions and measurement procedures from 40 CFR 86.1868–12 and 1066.845, which are used by manufacturers for compliance with fuel economy standards as described in 40 CFR 600.510(c)(3).

We are proposing to amend useful life specifications in 40 CFR 86.1805–12 and 86.1805–17 by removing references to useful life for GHG standards. Useful life for all criteria exhaust, evaporative, and refueling emission standards and onboard diagnostics would remain unchanged.

We are proposing to amend labeling requirements in 40 CFR 86.1807–01 by removing the requirement for battery electric vehicles and plug-in hybrid electric vehicles to identify monitor family and battery durability family on the vehicle emission control information label. We are proposing to remove the battery monitoring and battery durability requirements in 40 CFR 86.1815–27 and therefore no longer to include this family information as part of the certification process.

We are proposing to amend 40 CFR 86.1810–09(f)(2) by removing references to GHG emission standards. Manufacturers must continue to comply with altitude-related demonstration requirements for vehicles subject to the cold temperature standards for nonmethane hydrocarbon emissions.

We are proposing to amend 40 CFR 86.1810–17(j) by removing references to GHG emission standards. Small-volume manufacturers that modify a vehicle already certified by a different company must continue to meet other requirements as specified, such as those related to criteria exhaust, evaporative, and refueling emissions and onboard diagnostics.

We are proposing to amend 40 CFR 86.1811–17, 86.1811–27, and 86.1816–18 by removing references to GHG emission standards. We are not

otherwise proposing to change these sections, which establish criteria exhaust emission standards for light-duty and medium-duty vehicles.

We are proposing to remove 40 CFR 86.1815. We adopted this section to establish battery monitoring and battery durability requirements for battery electric vehicles and plug-in hybrid electric vehicles. Those battery-related requirements were adopted as part of the overall program for controlling GHG emissions. Since the earliest battery monitoring and battery durability requirements were scheduled to start in MY 2027, removing those requirements involves no immediate transition to discontinue compliance for certified vehicles.

We are proposing to remove 40 CFR 86.1818–12 and 86.1819–14. These sections describe the GHG standards and implementing provisions for MY 2010 and later light-duty vehicles and for MY 2014 and later medium-duty vehicles. We propose to discontinue the requirement to demonstrate compliance with these GHG standards and further propose that this discontinuation would apply as of the effective date of the final rule. Manufacturers need not amend existing certificates for ongoing production for the current model year. Manufacturers would in any case not need to submit credit reports at the end of the current model year to demonstrate compliance with the fleet average CO₂ standards.

We are proposing to amend test group specifications in 40 CFR 86.1823–08 by removing durability demonstration requirements related to GHG emission standards.

We are proposing to amend the provisions for establishing test groups in 40 CFR 86.1827–01 by removing the reference to CO₂ emission standards.

We are proposing to amend testing specifications in 40 CFR 86.1829–15 by removing references to GHG emission standards, except where needed to account for emission measurements related to fuel economy labeling. We are also proposing to change the nomenclature for the reference brake-specific CO₂ emission rate needed to perform calculations related to in-use testing for engines certified under 40 CFR 1036.635 for use in vehicles with high towing capacity.

We are proposing to amend the compliance provisions 40 CFR 86.1835–01, 86.1838–01, 86.1841–01, 86.1848–10, and 86.1854–12 by removing references to GHG emission standards.

We are proposing to amend carryover testing provisions in 40 CFR 86.1839–01 by removing references to accuracy requirements for battery monitoring for

¹²⁵ 81 FR 73478 (Oct. 25, 2016).

electric vehicles and plug-in hybrid electric vehicles.

We are proposing to amend instructions for the application for certification in 40 CFR 86.1844–01 by removing references to refrigerant leakage rates and GHG emission standards.

We are proposing to amend in-use testing requirements in 40 CFR 86.1845–04 and 86.1846–01 by removing references to testing GHG emissions and testing related to battery monitor accuracy and battery durability for electric vehicles and plug-in hybrid electric vehicles. We are also proposing to amend 40 CFR 86.1845–04 by changing the nomenclature for the reference brake-specific CO₂ emission rate needed to perform calculations related to in-use testing for engines certified under 40 CFR 1036.635 for use in vehicles with high towing capacity.

We are proposing to amend the credit provisions for criteria exhaust and evaporative emissions in 40 CFR 86.1861–17 by referencing the credit provisions in 40 CFR part 1036, subpart H, instead of 40 CFR part 1037, subpart H. We are proposing to remove the credit provisions in 40 CFR part 1037, subpart H, in this rule because they are needed only in relation to the GHG standards in 40 CFR part 1037, which we are proposing to remove in this rule. The referenced credit provisions in 40 CFR part 1037, subpart H, are equivalent to the analogous credit provisions in 40 CFR part 1036, subpart H. We are also proposing to amend 40 CFR 86.1861–17 by removing a reference to 40 CFR 86.1865(j)(3), which we are proposing to remove in this action.

We are proposing to remove 40 CFR 86.1865–12. This section describes the emission credit provisions related to the fleet average GHG standards. See the discussion related to 40 CFR 86.1818–12 and 86.1819–14 for the transition to discontinued GHG standards for the

model year currently in production for the year when the final rule is effective. More specifically, we are proposing no longer to recognize manufacturers' positive or negative GHG credit balances as of the effective date of the final rule. Note also that we are proposing to remove 40 CFR 86.1865–12(j)(3), which describes recall provisions for vehicles that do not comply with GHG standards. We recognize that a credit-based approach to recall is no longer appropriate without a GHG credit program. Accordingly, we are proposing to remove the provisions describing a credit-based remedy for noncompliance that does not involve a vehicle defect that can be repaired to bring vehicles into compliance with standards.

We are proposing to remove 40 CFR 86.1866–12, 86.1867–12, and 86.1867–31. These sections describe GHG credit programs for advanced technology and air conditioning leakage that serve only in relation to the GHG standards that we are proposing to remove in this rule.

We are proposing to amend the credit provisions for air conditioning efficiency and for off-cycle technologies in 40 CFR 86.1868–12 and 86.1869–12 by removing references to the fleet average GHG standards and adjusting the description to clarify that these credit provisions continue to serve as inputs for calculating fuel consumption improvement values and average fuel economy for light-duty program vehicles under 40 CFR 600.510. The 2024 final rule included new standards for light-duty program vehicles and several changes related to these credit programs, and we are not reopening those decisions.¹²⁶ First, we adopted a change for both air conditioning efficiency credits and off-cycle credits to not allow vehicles without engines to generate those credits starting in model year 2027. Second, we created a schedule to phase down off-cycle credits for vehicles with engines by

establishing a declining value of the cap on off-cycle credits through model year 2032, with off-cycle credits fully discontinued for all vehicles starting in model year 2033. Third, we removed the option for manufacturers to generate off-cycle credits according to the provisions of 40 CFR 86.1869–12(c) and (d) starting in model year 2027.

We are proposing to remove 40 CFR 86.1870–12. This section describes a GHG credit program for full-size pickup trucks with hybrid technology. Those GHG credits were also used for calculating fuel consumption improvement values and average fuel economy for light-duty program vehicles under 40 CFR 600.510. However, we amended those credit provisions in the 2021 final rule to establish model year 2024 as the last year that manufacturers could generate those credits.¹²⁷ Because those credits are already discontinued for purposes of demonstrating compliance with EPA emission standards, manufacturers can no longer use those provisions to create fuel consumption improvement values under 40 CFR part 600.

c. 40 CFR Part 600—Requirements Related to Fuel Economy for Light- and Medium-Duty Vehicles

In general, we propose to amend 40 CFR part 600 to remove all references to GHG emission standards and related provisions while retaining provisions that support compliance with CAFE standards and fuel economy labeling for passenger cars and light trucks. In the remainder of this subsection, we describe several proposed amendments that are needed to remove GHG-related provisions from 40 CFR part 600 without affecting provisions related to CAFE standards and fuel economy labeling. Table 3 provides a summary of the regulations we propose either to remove or to amend in 40 CFR part 600.

TABLE 3—SUMMARY OF PROPOSED CHANGES TO LIGHT-DUTY AND MEDIUM-DUTY HIGHWAY ENGINE REGULATIONS UNDER 40 CFR PART 600

40 CFR part 600	Sections proposed to remove	Sections proposed to amend
Subpart A—General Provisions .....	.....	600.001, 600.002, 600.006, 600.007, 600.008, 600.010.
Subpart B—Fuel Economy and Exhaust Emission Test Procedures. ....	.....	600.101, 600.111–08, 600.113–12, 600.114–12, 600.116–12, 600.117.
Subpart C—Procedures for Calculating Fuel Economy and Carbon-related Exhaust Emission Values. ....	.....	600.206–12, 600.207–12, 600.210–12.
Subpart F—Procedures for Determining Manufacturer's Average Fuel Economy.	600.514–12	600.507–12, 600.509–12, 600.510–12, 600.512–12.

¹²⁶ 89 FR 27842 (Apr. 18, 2024).

¹²⁷ 86 FR 74434 (Dec. 30, 2021).

We are proposing to amend the applicability statements in 40 CFR 600.001 by removing references to carbon-related exhaust emissions and fleet average CO₂ standards. We are also proposing to remove the reference in 40 CFR 600.001(a) to medium-duty vehicles because we are proposing to revise 40 CFR part 600 such that those vehicles would no longer be subject to regulation under 40 CFR part 600. In contrast, the testing provisions would remain to describe how passenger automobiles and light trucks (including medium-duty passenger vehicles) must meet fuel economy standards and how manufacturers must prepare fuel economy labels.

We are proposing to amend the definitions in 40 CFR 600.002 by removing the reference to fleet average CO₂ standards. We are also proposing to remove the portions of several definitions that relate to medium-duty vehicles (also described as heavy-duty vehicles in the regulation).

We are proposing to amend the definition of Medium-Duty Passenger Vehicle (MDPV_{FE}) for purposes of fuel economy testing and reporting in 40 CFR 600.002 to align with the clarified definition published by NHTSA at 49 CFR 523.2 (89 FR 52945, June 24, 2024). Aligning these definitions is necessary to ensure EPA's test procedures are properly applied to vehicles covered by fuel economy standards and labeling requirements.

As described for 40 CFR 86.1803–01, we are proposing to amend several references across 40 CFR part 600 to change from a generic reference to “configuration” and replace it with the specific reference to “vehicle configuration.”

We are proposing to amend the information requirements in 40 CFR 600.006 through 600.010 by removing references to carbon-related exhaust emissions, GHG emission standards, and reporting GHG-related information generally.

We are proposing to amend the testing overview in 40 CFR 600.101 and 600.111–08 by removing references to carbon-related exhaust emissions and fleet average CO₂ emissions.

We are proposing to amend the emission calculations in 40 CFR 600.113–12 by removing references to carbon-related exhaust emissions and other GHG emissions.

We are proposing to amend the interim testing provisions in 40 CFR 600.117 by removing paragraph (a)(5) since we are proposing to discontinue GHG testing with in-use vehicles under 40 CFR 86.1845–04. We are also proposing to revise paragraphs (a)(6)

and (b) to clarify that manufacturers do not adjust measured fuel economy values to account for fuel effects, whether they test with E0 or E10 gasoline.

We are proposing to amend the testing, calculation, and reporting specifications in 40 CFR 600.116–12, 600.507–12, 600.509–12, and 600.510–12 by removing references to carbon-related exhaust emissions. We note that calculations related to off-cycle credits in 40 CFR 600.510(c)(3)(ii) continue to rely on carbon-related exhaust emissions as specified in 40 CFR 86.1869–12.

We are proposing to amend the reporting requirements in 40 CFR 600.512–12 by removing references to carbon-related exhaust emissions. This includes amending 40 CFR 600.512–12(c)(5)(i) to explain that the purpose for performing the calculations in 40 CFR 600.510–12(c)(3) is to support credit calculations for fuel economy improvement factors, rather than demonstrating compliance with the fleet average standard for carbon-related exhaust emissions. We are proposing to move the existing reporting requirement for emission credits related to fuel consumption improvement values from 40 CFR 86.1865–12(l)(2)(iii), which we are proposing to remove, to 40 CFR 600.512–12(c)(3) to preserve the existing provisions needed for fuel economy reporting. We are also proposing to remove the reporting requirements in 40 CFR 600.514–12, which are solely related to GHG emissions.

C. Heavy-Duty Engine and Vehicle GHG Program

This subpart includes background on EPA's heavy-duty GHG emission program and describes our proposed changes to the engine-based GHG regulations and our proposed changes to the vehicle-based GHG regulations.

1. Background on the Heavy-Duty Engine and Vehicle GHG Program

The EPA promulgated new GHG emission standards for heavy-duty engines and vehicles in three separate rulemakings. In 2011, the EPA established the first GHG standards for model year 2014 and later heavy-duty engines and vehicles in an action titled “Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles” (HD GHG Phase 1).¹²⁸ In 2016, the EPA set new GHG standards for model year 2021 and later heavy-duty engines and vehicles in an action titled “Greenhouse Gas Emissions and Fuel Efficiency

Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2” (HD GHG Phase 2).¹²⁹ Most recently, in 2024, the EPA finalized an action titled “Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles—Phase 3” (HD GHG Phase 3), which set new CO₂ emission standards for model year 2032 and later heavy-duty vehicles that phase in starting as early MY 2027 for certain vehicle categories.¹³⁰ The phase-in revises MY 2027 GHG standards that were established previously under the EPA's HD GHG Phase 2 rulemaking.¹³¹

The EPA and NHTSA jointly issued the HD GHG Phase 1 and HD GHG Phase 2 rulemakings covering heavy-duty GHG emission and fuel efficiency standards. The EPA set GHG emission standards under CAA section 202(a), and NHTSA set fuel consumption standards under EISA.¹³² The EPA and NHTSA programs are harmonized through MY 2026; however, NHTSA has not adopted changes in fuel consumption standards corresponding to the EPA's HD GHG Phase 3 standards. As a result, the CO₂ emission and fuel consumption standards currently diverge in MY 2027 and later.

The EPA's regulations include the test procedures along with a certification and compliance program, which is led by the EPA. As noted previously, this regulatory structure was designed to maximize efficiency within the Federal government and minimize the burden on the engine and vehicle manufacturers by centralizing data submission. Manufacturers submit data and information to the EPA and the EPA, in turn, shares information with NHTSA as needed to support NHTSA's implementation of its fuel consumption standards.¹³³

2. Proposed Changes to the Heavy-Duty Engine and Vehicle GHG Regulations

The EPA's heavy-duty engine and vehicle emission regulations are contained in two standard-setting parts. 40 CFR part 1036 includes the engine-based emissions regulations for both criteria pollutant and GHG emissions.¹³⁴ 40 CFR part 1037 includes the vehicle-based emission regulations for criteria pollutant exhaust emissions,

¹²⁹ 81 FR 73478 (Oct. 25, 2016).

¹³⁰ See 89 FR 29559–29561 (Apr. 22, 2024).

¹³¹ 89 FR 29440 (Apr. 22, 2024).

¹³² 49 U.S.C. 32902(k).

¹³³ See 49 CFR 535.8, 1036.755, 1037.755.

¹³⁴ Note that heavy-duty engine manufacturers are subject to criteria pollutant standards in 40 CFR part 86, subpart A, through 2026. In a recent rulemaking (88 FR 4296, Jan. 24, 2023), the EPA migrated criteria pollutant regulations from 40 CFR part 86, subpart A, to 40 CFR part 1036 with new requirements that apply to 2027 and later heavy-duty engines. See 88 FR 4326.

¹²⁸ 76 FR 57106 (Sept. 15, 2011).

evaporative and refueling emissions, and GHG emissions.

In the following subsections, we describe our proposed removal and amendment of specific portions of each of these regulatory parts. In general, the approach taken in this proposal is to remove the MY 2014 and later heavy-duty GHG emission standards promulgated in HD GHG Phase 1, Phase 2, and Phase 3, collectively, along with the testing and reporting requirements associated with the GHG emission standards. We request comment on the proposed regulatory changes and whether additional changes are necessary to remove GHG regulations.

a. 40 CFR Part 1036—Emission Standards and Compliance Provisions for Heavy-Duty Engines

40 CFR part 1036 contains regulations related to the final rule titled “Control of Emissions from New and In-Use Heavy-Duty Highway Engines,” including emission standards and compliance provisions for criteria pollutant emissions, evaporative and

refueling emissions, and GHG exhaust emissions (*i.e.*, CO₂, N₂O, and methane). 40 CFR part 1036 is divided into nine subparts with three appendices. Subpart A defines the applicability of part 1036 and gives an overview of regulatory requirements. Subpart B describes the emission standards and other requirements that must be met to certify engines under this part. Subpart C describes how to apply for a certificate of conformity for heavy-duty engines. Subpart D addresses testing of production engines and hybrid powertrains. Subpart E addresses in-use testing, while Subpart F describes how to test engines to demonstrate compliance with the criteria pollutant and GHG emission standards. Subpart G describes requirements, prohibitions, and other provisions that apply to engine manufacturers, vehicle manufacturers, owners, operators, rebuilders, and all others. Subpart H describes how manufacturers can optionally generate, bank, trade, and use emission credits to certify heavy-duty engines. Subpart I includes definitions

and other reference material. Appendix A includes a summary of previous emissions standards. Appendix B includes the transient duty cycles. Appendix C includes engine fuel maps used in the certification of specific vehicles to meet the heavy-duty vehicle CO₂ emission standards.

This subsection includes an overview of the regulations related to the heavy-duty engine program we propose to remove or revise. In general, we propose to amend 40 CFR part 1036 to remove all GHG emission standards, references to such standards, and related provisions; however, most of 40 CFR part 1036 is retained for EPA’s heavy-duty engine criteria pollutant emission program. In this subsection, we describe the proposed amendments to remove GHG-related provisions from 40 CFR part 1036, which include some amendments needed to retain, without reopening, the efficacy of the criteria pollutant emission standards. Table 4 provides a summary of the regulations we propose either to remove or to amend in 40 CFR part 1036.

TABLE 4—SUMMARY OF PROPOSED CHANGES TO HEAVY-DUTY HIGHWAY ENGINE REGULATIONS UNDER 40 CFR PART 1036

40 CFR part 1036	Sections proposed to remove	Sections proposed to amend
Subpart A—Overview and Applicability .....	.....	1036.1, 1036.5, 1036.15.
Subpart B—Emission Standards and Related Requirements.	1036.108	1036.101, 1036.115, 1036.130, 1036.135, 1036.150.
Subpart C—Certifying Engine Families	1036.241	1036.205, 1036.225, 1036.230, 1036.231, ^a 1036.235, 1036.245.
Subpart D—Testing Production Engines and Hybrid Powertrains.	.....	1036.301.
Subpart E—In-Use Testing .....	.....	1036.415.
Subpart F—Test Procedures	1036.505, 1036.535, 1036.540, 1036.543, 1036.550.	1036.501, 1036.510, 1036.512, 1036.514, 1036.520, 1036.530, 1036.545, 1036.580.
Subpart G—Special Compliance Provisions	1036.610, 1036.615, 1036.620, 1036.625, 1036.630, 1036.635.	1036.605. ^b
Subpart H—Averaging, Banking, and Trading for Certification.	1036.745, 1036.755	1036.701, 1036.705, 1036.710, 1036.720, 1036.725, 1036.730, 1036.740, 1036.750.
Subpart I—Definitions and Other Reference Information.	.....	1036.801, 1036.805, 1036.810, 1036.815.
Appendices	Appendix C.	

^a We are proposing to move 40 CFR 1037.231 to a new 40 CFR 1036.231.

^b We are proposing similar revisions in 40 CFR 86.007–11(g) and 86.008–10(g) for model year 2026 and earlier engines for specialty vehicles.

Within 40 CFR part 1036, subpart B, we propose to remove 40 CFR 1036.108, which includes the GHG emission standards for CO₂, N₂O, and methane. We also propose to remove several paragraphs from 40 CFR 1036.150 that describe interim provisions related to the heavy-duty engine or vehicle GHG programs. We propose to remove and reserve 40 CFR 1036.150(b), (d), (e), (g)–(j), (l)–(n), (p)–(s), and (w) and otherwise to retain the existing section numbering. We propose to remove 40 CFR 1036.150(aa) at the end of the section.

In 40 CFR part 1036, subpart C, we propose to remove 40 CFR 1036.230(f) and (g), which describe how manufacturers divide their product lines into engine families for certifying to the GHG emission standards. We propose several revisions in 40 CFR 1036.235 to remove GHG emission testing requirements. In 40 CFR 1036.235(a), we propose to migrate text from 40 CFR 1037.235(a) that provides direction on how manufacturers select the test powertrain to replace GHG-related testing requirements in 40 CFR 1036.235(a)(2). We propose to remove in

its entirety 40 CFR 1036.241, which describes how to demonstrate compliance with the heavy-duty engine GHG emission standards. In 40 CFR 1036.245, existing provisions allow manufacturers to use vehicle-based duty cycles for engine service accumulation in the laboratory to determine deterioration factors. As described in section VI.C.2.b of this preamble, we are proposing to remove the referenced vehicle-based duty cycles from 40 CFR part 1037, so we are proposing to revise 40 CFR 1036.245(c)(3)(ii) to allow manufacturers to request approval of a

different test sequence, without requiring specific duty cycles.

Also in 40 CFR part 1036, subpart C, we propose to migrate the provisions that relate to powertrain families from the vehicle standard-setting part in 40 CFR 1037.231 to the engine standard-setting part as a new 40 CFR 1036.231 with proposed revisions described in this section. In a previous rule (89 FR 29616), we migrated the powertrain test procedure from the heavy-duty vehicle procedures (formerly 40 CFR 1037.550) to the heavy-duty engine procedures in 40 CFR 1036.545 because we expected powertrain testing to be primarily used by engine manufacturers in certifying engines to criteria pollutant standards or in place of engine-based procedures for GHG standards. Similarly, we are proposing to migrate the related provisions manufacturers would use to divide their product line into powertrain families. In general, we propose to migrate the text from the vehicle program in 40 CFR 1037.231 to a newly created section in the engine program under 40 CFR 1036.231. We propose to modify the text previously under 40 CFR 1037.231(b)(1), such that the new 40 CFR 1036.231(b)(1) would no longer require powertrains to share the same engine families described in 40 CFR 1036.230 but would require the engine share the same design aspects specified in 40 CFR 1036.230. Since a manufacturer may choose to certify the whole powertrain to the standards in 40 CFR part 1036, there would only be a powertrain family, not a certified engine family that contains just the engine. Similarly, and consistent with our approach for defining engine families in 40 CFR 1036.230, we see no need to limit the powertrain family based on the vehicle service class the powertrain goes into and propose not to migrate the existing 40 CFR 1037.231(b)(2) that requires powertrain families to share vehicle service class groupings. We are also proposing not to migrate “energy capacity” as an example attribute in the proposed new 40 CFR 1036.231(b)(10), since it is not needed for the criteria pollutant standards. Similarly, we are proposing not to migrate existing 40 CFR 1037.231(b)(11) since rated output of hybrid mechanical power technology is also not needed for a criteria pollutant family definition.

In 40 CFR part 1036, subpart D, we propose to revise 40 CFR 1036.301 to remove paragraphs (a) through (d) describing how the EPA would conduct selective enforcement audits related to heavy-duty CO₂ engine emissions. We propose to revise the existing statement that selective enforcement audits apply for engines as specified in 40 CFR part

1068, subpart E, by adding that they apply for powertrains, consistent with 40 CFR 1036.301(c) which we are proposing to remove.

As previously noted, we are retaining and not reopening the in-use testing procedures in 40 CFR part 1036, subpart E, which apply for the criteria pollutant emission standards. More specifically, within the in-use test procedures, we are retaining references to measuring CO₂ for use in required chemical balance test procedures and to calculate the criteria pollutant emissions values for in-use testing. Also, in 40 CFR 1036.415(g), we continue to require that manufacturers override any adjustable idle-reduction features on vehicles used for in-use testing; however, we propose to revise the text to include a more general statement describing what it means to be adjustable.

In 40 CFR part 1036, subpart F, we propose to remove test procedures related to developing engine data to support heavy-duty vehicle GHG emissions certification, which include 40 CFR 1036.505, 1036.535, 1036.540, 1036.543, and 1036.550. Relatedly, we propose to remove the fuel map duty cycle in Appendix C to part 1036. In 40 CFR 1036.510, we propose several revisions to paragraph (b), including replacing a reference to 40 CFR 1036.540(c)(2) with a new table that provides the gear ratios based on engine service class from 40 CFR 1036.540. We also propose to remove and reserve 40 CFR 1036.510(e) and 1036.512(e), which describe how to determine GHG emissions for plug-in hybrid powertrains using the heavy-duty engine Federal Test Procedure (FTP) and engine Supplemental Emissions Test (SET) and duty cycles, respectively. In 40 CFR 1036.530(e), we are retaining and not reopening the requirement that manufacturers measure CO₂ emissions for in-use testing, but we propose to revise the related variable e_{CO_2FTPCL} to remove reference to “family certification limit (FCL)” that would no longer apply. The proposed new variable, e_{CO_2FTP} , would represent the engine’s brake-specific CO₂ over the FTP or SET duty cycle. Relatedly, we are proposing to replace references to e_{CO_2FTPCL} with e_{CO_2FTP} throughout 40 CFR parts 1036 and 1037.

Powertrain testing, also described in 40 CFR part 1036, subpart F, is an option that manufacturers may use for certifying hybrid powertrains to the engine criteria pollutant standards in 40 CFR 1036.104 and the GHG emission standards in 40 CFR 1036.108. The powertrain test procedure in 40 CFR 1036.545 describes testing a powertrain that includes an engine coupled with a

transmission, drive axle, and hybrid components, or a subset of these components. We are retaining without reopening most of 40 CFR 1036.545 related to the powertrain testing for criteria pollutants, but we propose to remove the portions related to the GHG program and revise several paragraphs to account for the removed GHG content. Throughout 40 CFR 1036.545, we propose to remove existing requirements to create inputs for EPA’s Greenhouse gas Emission Model (GEM) tool that manufacturers use for compliance with the CO₂ standards. We also propose to remove references to the use of utility factors, vehicle configurations, and vehicle-based duty cycles and test procedures. In 40 CFR 1036.545(b), (d), and (j) we propose to replace 40 CFR part 1037 references with relevant text from the procedures. We also propose to remove paragraph (p) which describes the procedure to determine usable battery energy for plug-in hybrid powertrains.

As noted in 40 CFR 1036.545(a), powertrain testing depends on vehicle and component models to test the powertrain using the engine-based duty cycles and the existing 40 CFR 1036.545(a), (f), and (g), and allow manufacturers to use the hardware-in-the-loop (HIL) model included in GEM. As described in section VI.C.2.b of this preamble, we propose to remove GHG vehicle testing requirements for most vehicles, including any requirements to use GEM to demonstrate compliance. However, we propose to retain the use of the HIL model within GEM Phase 2, Version 4.0 for the powertrain test procedure.¹³⁵

In 40 CFR part 1036, subpart G, we propose revisions to 40 CFR 1037.605 to remove the GHG requirements for engines installed in specialty vehicles and are proposing to make similar changes in 40 CFR 86.007–11(g) and 86.008–10(g) for model year 2026 and earlier specialty vehicle engines. We propose to remove 40 CFR 1036.610 through 1036.630, which include compliance provisions related to heavy-duty engine GHG emissions compliance. We propose also to remove 40 CFR 1036.635, which describes how manufacturers that certify engines for use in high-gross combined vehicle weight (GCWR) medium-duty vehicles under 40 CFR part 1036 could comply with GHG standards under 40 CFR part 86, subpart S. With no need to describe the GHG-related flexibilities in 40 CFR 1036.635, the existing applicability

¹³⁵ GEM Phase 2, Version 4.0 is incorporated by reference in 40 CFR 1036.545. See also 40 CFR 1036.810.

provisions in 40 CFR 1036.1 and 1036.5 already cover the certification provisions for high-GCWR vehicles as they relate to criteria pollutants. Specifically, 40 CFR 1036.1 sets up the default of applying the standards and certification requirements from 40 CFR part 1036 to all engines installed in heavy-duty vehicles (generally vehicles above 8,500 pounds GVWR), while 40 CFR 1036.5 allows manufacturers to certify medium-duty vehicles to the chassis-based program as described in 40 CFR 86.1801–12. We are proposing to make minor changes to 40 CFR 1036.5(a) to differentiate more clearly the certification requirements for medium-duty vehicles from those for heavy-duty engines.

In 40 CFR part 1036, subpart H, we propose to remove 40 CFR 1036.745, which describes CO₂ emission credit deficits.

In 40 CFR part 1036, subpart I, we propose to remove GHG-specific symbols, abbreviations, and acronyms from 40 CFR 1036.805, and propose to remove materials from 40 CFR 1036.810 that are only incorporated by reference in the test procedures we propose to remove. In 40 CFR 1036.801, we propose to remove several GHG-specific definitions, and are moving transmission- and other powertrain-related definitions from the heavy-duty

vehicle definitions in 40 CFR 1037.801 to the engine definitions in 40 CFR 1036.801, so they can be available to engine manufacturers using the powertrain test procedures in 40 CFR 1036.545.

b. 40 CFR Part 1037—Emission Standards and Compliance Provisions for Heavy-Duty Vehicles

40 CFR part 1037 contains regulations related to the final rule titled “Control of Emissions from New Heavy-Duty Motor Vehicles,” including GHG emission standards for CO₂ and HFC, criteria pollutant emission standards that apply for all heavy-duty vehicles, and evaporative and refueling emission standards that apply for certain heavy-duty vehicles. 40 CFR part 1037 is divided into nine subparts with five appendices. Subpart A defines the applicability of part 1037 and gives an overview of regulatory requirements. Subpart B describes the emission standards and other requirements that must be met to certify vehicles under this part. Subpart C describes how to apply for a certificate of conformity. Subpart D and E address testing of production and in-use vehicles, respectively. Subpart F describes how to test vehicles and perform emission modeling for vehicles subject to the CO₂ emission standards. Subpart G, along

with 40 CFR part 1068, describe requirements, prohibitions, and other provisions that apply to manufacturers, owners, operators, rebuilders, and all others. Subpart H describes how manufacturers can optionally generate and use emission credits to certify vehicles. Subpart I includes definitions and other reference material. Finally, Appendix A, B, and D include test cycles, Appendix C presents emission control identifiers for emissions labels, and Appendix E presents power take-off utility factors.

This subsection includes an overview of the regulations related to the heavy-duty vehicle program we propose to remove or revise. In general, we propose to amend 40 CFR part 1037 to remove all GHG emission standards, references to such standards, and related provisions without revising or reopening provisions necessary to support criteria pollutant standards, including evaporative and refueling emissions standards. Below we describe the proposed amendments to remove GHG-related provisions from 40 CFR part 1037, which include some amendments needed to retain the efficacy of the criteria pollutant emission standards. Table 5 provides a summary of the regulations we propose either to remove or to amend in 40 CFR part 1037.

TABLE 5—SUMMARY OF PROPOSED CHANGES TO HEAVY-DUTY HIGHWAY VEHICLE REGULATIONS UNDER 40 CFR PART 1037

40 CFR part 1037	Sections proposed to remove	Sections proposed to amend
Subpart A—Overview and Applicability .....	.....	1037.5, 1037.10, 1037.15.
Subpart B—Emission Standards and Related Requirements.	1037.105, 1037.106, 1037.140, 1037.150	1037.101, 1037.102, 1037.115, 1037.120, 1037.125, 1037.135.
Subpart C—Certifying Vehicle Families	1037.231, ^a 1037.232	1037.201, 1037.205, 1037.225, 1037.230, 1037.235, 1037.250.
Subpart D—Testing Production Vehicles and Engines.	1037.301, 1037.305, 1037.315, 1037.320.	
Subpart E—In-Use Testing	1037.401.	
Subpart F—Test and Modeling Procedures	1037.501, 1037.510, 1037.520, 1037.525, 1037.527, 1037.528, 1037.530, 1037.532, 1037.534, 1037.540, 1037.551, 1037.555, 1037.560, 1037.565, 1037.570.	
Subpart G—Special Compliance Provisions	1037.610, 1037.615, 1037.630, 1037.631, 1037.640, 1037.645, 1037.655, 1037.660, 1037.665, 1037.670.	1037.601, 1037.605, 1037.620, 1037.621, 1037.622, 1037.635.
Subpart H—Averaging, Banking, and Trading for Certification.	1037.701, 1037.705, 1037.710, 1037.715, 1037.720, 1037.725, 1037.730, 1037.735, 1037.740, 1037.745, 1037.750, 1037.755.	
Subpart I—Definitions and Other Reference Information.	1037.810	1037.801, 1037.825.
Appendices	Appendices A, B, C, D, E.	

^aWe are proposing to move 40 CFR 1037.231 to a new 40 CFR 1036.231.

In 40 CFR part 1037, subpart A, we are retaining and not proposing to reopen the existing applicability of 40 CFR part 1037. Specifically, as described in existing 40 CFR 1037.1, the

part would continue to apply for battery electric vehicles, fuel cell electric vehicles, and vehicles fueled by conventional and alternative fuels.

Existing 40 CFR part 1037, subpart B, includes criteria pollutant exhaust emission standards, evaporative and refueling emission standards, and GHG emission standards that apply at the

vehicle level. In 40 CFR part 1037, subpart B, we propose to remove the MY 2014 and later heavy-duty vehicle CO₂ emission standards promulgated in HD GHG Phase 1, Phase 2, and Phase 3. This includes the vocational vehicle standards in 40 CFR 1037.105 and the tractor standards in 40 CFR 1037.106. We also propose to amend 40 CFR 1037.115 to remove the HFC emission standards. We propose to amend 40 CFR 1037.120 to remove the emission control components related to heavy-duty vehicle GHG-reducing technologies. We are retaining and not proposing to reopen the requirement that the basic emission-related warranty applies for fuel cell stacks and rechargeable energy storage systems (RESS) as they continue to qualify as an emission-related component related to criteria pollutant emission standards. Similarly, we are retaining and not proposing to reopen the emission control components covering a vehicle's evaporative and refueling emissions. Also in Subpart B, we propose to remove 40 CFR 1037.140 and 1037.150, which include the vehicle classifications and interim provisions related directly to the heavy-duty vehicle GHG emission standards.

While we propose to remove GHG standards and related requirements, we would retain without reopening criteria pollutant exhaust emission standards in 40 CFR 1037.102 and the evaporative and refueling emission standards in 40 CFR 1037.103. We propose to revise 40 CFR 1037.102(a) to describe how vehicles can be deemed to meet the criteria pollutant exhaust emission standards without testing under 40 CFR part 1037. As proposed, vehicle manufacturers would continue to submit an application for certification meeting the applicable requirements in 40 CFR 1037.205, affix an appropriate label to their vehicles as specified in 40 CFR 1037.135, and meet the applicable reporting and recordkeeping requirements in 40 CFR 1037.250. Under this proposed approach, most heavy-duty vehicles would be deemed to meet the criteria pollutant exhaust emissions standards if manufacturers state in their applications for certification that the installed engines are certified to the standards of 40 CFR part 86 or 1036, as applicable. We similarly propose specialty vehicles meeting the requirements in 40 CFR 1037.605 and heavy-duty glider vehicles meeting the requirements 40 CFR 1037.635 would also be deemed to meet the criteria pollutant exhaust emission

standards.¹³⁶ Existing 40 CFR part 1037 includes other requirements that would continue to apply for certain vehicles, and we propose to revise 40 CFR 1037.102(a) to also refer to the requirements we are retaining and not reopening for auxiliary power units (APUs) installed on new tractors, now specified in proposed new 40 CFR 1037.102(c), and for the vehicles subject to the existing evaporative and refueling emission standards that apply as specified in 40 CFR 1037.103.

In the HD GHG Phase 2 rulemaking, we adopted PM emission standards that apply for APUs installed on new tractors.¹³⁷ The APU requirements are currently specified in 40 CFR 1037.106 with the other tractor standards, including the GHG emission standards we are proposing to remove. Since PM emissions are criteria pollutant emissions, we are retaining and not reopening the PM emission standards for APUs, and we propose to migrate 40 CFR 1037.106(g) to a new 40 CFR 1037.102(c). We note that the APUs under this specific proposed revision are certified under the nonroad compression-ignition engine regulations in 40 CFR part 1039, and existing 40 CFR 1039.699 includes references to the APU standards in 40 CFR part 1037. We propose to modify 40 CFR 1039.699(a) and (n) to refer to the proposed new 40 CFR 1037.102 instead of 40 CFR 1037.106, which we propose to remove.

In 40 CFR part 1037, subpart C, we propose to remove 40 CFR 1037.231, 1037.232, and 1037.241 that only apply for certifying heavy-duty vehicles to the GHG emission standards. We are retaining 40 CFR 1037.235, which remains applicable for evaporative and refueling testing that we are not reopening, with proposed revisions to remove GHG-related testing requirements. Existing 40 CFR 1037.230 directs manufacturers to divide their product lines into vehicle families based on regulatory subcategories; however, with the proposed removal of GHG standards, we also propose to remove the range of GHG-based vehicle regulatory subcategories. Therefore, for the purpose of defining vehicle families, we propose to amend 40 CFR 1037.230 to reflect the vehicle types outlined in the proposed 40 CFR 1037.102. Specifically, we propose that manufacturers would create a single vehicle family for all vehicles with propulsion engines that are certified to the criteria pollutant standards of 40

CFR 86.007–11 or 86.008–10, or 40 CFR part 1036, except that new tractors with auxiliary power units would be in a separate family, and vehicles subject to evaporative or refueling standards would be in families as described in existing 40 CFR 86.1812. We propose all specialty vehicles would be a single vehicle family, and all glider vehicles would be in a single vehicle family. Finally, we propose that all vehicles with no propulsion engine, such as battery electric vehicles and fuel cell electric vehicles, would be in a single vehicle family.

With the updated vehicle families, we propose to revise 40 CFR 1037.205, which defines what manufacturers would include in their application for certification. The proposed 40 CFR 1037.205 includes existing information required for all applications for certification, and more clearly defines what specific information would be required for each of the vehicle families proposed in 40 CFR 1037.230.

We propose to remove 40 CFR part 1037, subpart D, in its entirety because it describes the testing of production vehicles to be certified to the heavy-duty CO₂ emission standards. The provisions in 40 CFR 1037.301 through 1037.320 include audit procedures for inputs to the Greenhouse gas Emissions Model (GEM), tractor aerodynamic testing, powertrain testing, and axle and transmission testing.

We propose to remove 40 CFR part 1037, subpart E, in its entirety because it includes the requirements for testing of in-use vehicles and applies only to GHG emission standards.

We propose to remove 40 CFR part 1037, subpart F, in its entirety because it includes the testing and modeling provisions necessary to certify heavy-duty vehicles to the CO₂ emission standards. The provisions in 40 CFR 1037.501 through 1037.570 include procedures for vehicle-based duty cycles for measuring GHG emissions, aerodynamic testing, powertrain component testing, testing with hybrid power take-off units, and the use of GEM.

We propose to remove several sections of 40 CFR part 1037, subpart G, relating to special compliance provisions for the heavy-duty vehicle GHG emission standards. Specifically, we propose to remove 40 CFR 1037.610 through 1037.615, 1037.630, 1037.631, and 1037.640 through 1037.670. These sections include provisions related to off-cycle technologies, advanced technologies, special purpose tractors, variable vehicle speed limiters, idle reduction technologies, in-use tractor

¹³⁶ See the discussion of 40 CFR part 1037, subpart G, for the revisions we propose related to the specialty vehicle and glider vehicle provisions.

¹³⁷ See 81 FR 73576–73580.

testing, and optional tractor CO₂ emission standards.

We propose to remove 40 CFR part 1037, subpart H in its entirety. The provisions of 40 CFR 1037.701 through 1037.750 describe the averaging, banking, and trading of CO₂ emission credits, along with associated recordkeeping and reporting requirements.

We propose several revisions in 40 CFR part 1037, subpart I, to remove GHG-specific definitions from 40 CFR 1037.801, and symbols, abbreviations, and acronyms from 40 CFR 1037.805. We also propose to remove 40 CFR 1037.810, which includes materials incorporated by reference to support testing to demonstrate compliance with the heavy-duty vehicle GHG standards. This includes, but is not limited to, the GEM model and test procedures for measuring the rolling resistance of tires, tire revolutions per mile, and aerodynamics using coastdown, wind tunnel, and computational fluid dynamics.

Lastly, we propose to remove all appendices to 40 CFR part 1037. Appendices A, B, and D include the test cycles related to heavy-duty vehicle GHG standards. Appendix C includes the emission control identifiers for GHG emission labels. Appendix E includes the power take-off unit utility factors applied in GHG-specific test procedures.

c. Relationship Between the EPA's GHG and NHTSA's Fuel Efficiency Medium- and Heavy-Duty Programs

The current certification and compliance process as relevant for NHTSA is as follows, separately for heavy-duty engines and heavy-duty vehicles:

1. Manufacturers submit fuel consumption data to the EPA using the EPA's electronic certification system following EPA test procedures included in 40 CFR parts 1036 and 1037;

2. The EPA issues certificates of conformity to the manufacturers;

3. Before and during the model year, the EPA sends the fuel consumption data and associated information to NHTSA;

4. After the model year, the EPA analyzes end-of-year reports submitted to the EPA by manufacturers for compliance and shares the fuel consumption data with NHTSA; and

5. NHTSA manages its compliance process related to the fuel consumption standards.

NHTSA's medium- and heavy-duty fuel efficiency regulations in 49 CFR part 535 refer to several sections in EPA's 40 CFR parts 1036 and 1037 that we are proposing to modify or remove.

The provisions NHTSA's regulations reference from EPA's heavy-duty engine regulations include 40 CFR 1036.1, 1036.108, 1036.150, 1036.205, 1036.225, 1036.230, 1036.235, 1036.250, 1036.255, 1036.301, 1036.501, 1036.505, 1036.510, 1036.512, 1036.525, 1036.535, 1036.540, 1036.545, 1036.620, 1036.725, 1036.730, 1036.740, 1036.745, and some definitions in 1036.801. The provisions NHTSA's regulations reference from EPA's heavy-duty vehicle regulations include 40 CFR 1037.105, 1037.106, 1037.140, 1037.150, 1037.205, 1037.210, 1037.225, 1037.230, 1037.232, 1037.250, 1037.255, 1037.301, 1037.305, 1037.320, 1037 subpart F broadly, 1037.510, 1037.520, 1037.525, 1037.527, 1037.528, 1037.530, 1037.532, 1037.534, 1037.540, 1037.560, 1037.565, 1037.570, 1037.601, 1037.605, 1037.610, 1037.615, 1037.620, 1037.621, 1037.622, 1037.631, 1037.660, 1037.725, 1037.730, 1037.740, 1037.745, 1037.755, and some definitions in 1037.801. We request comment on whether any of these provisions should be retained with a CFR notation throughout 40 CFR parts 1036 and 1037 explaining that these sections only apply to NHTSA's heavy-duty fuel efficiency program.

We propose to remove 40 CFR 1036.755 and 1037.755, which describe the information the EPA would provide to the Department of Transportation related to heavy-duty engine and vehicle fuel consumption. We note that NHTSA's reporting and recordkeeping regulation in 49 CFR 535.8(a)(6) directs manufacturers to submit information to EPA. 49 CFR 535.8(a)(6) also provides direction to manufacturers in instances where the EPA does not have an electronic pathway to receive the information, to send it through an electronic portal identified by NHTSA, through the NHTSA CAFE database, or to send hardcopy documents to the address provided in the regulations.¹³⁸ We request comment on the time required to transition from manufacturers supplying data to the EPA to supplying the data directly to NHTSA.

VII. Requests for Comment

The EPA is specifically soliciting comment on key aspects of the proposed rule. To facilitate comment on those portions of the rule, the EPA has indexed each comment solicitation with a unique identifier below (*e.g.*, "C-1", "C-2") to provide a consistent framework for effective and efficient provision of comments. Accordingly, we ask that commenters include the corresponding identifier when

providing comments relevant to that comment solicitation. We ask that commenters include the identifier either in a heading or within the text of each comment, to make clear which comment solicitation is being addressed. We note that we are not limiting comment to these identified areas. Specifically, we are soliciting comment on the following:

1. All aspects of this proposal, including legal and scientific developments that are being subject to public comment for the first time (C-1).

2. The scientific underpinnings of the Endangerment Finding are weaker than previously believed and contradicted by empirical data, peer-reviewed studies, and scientific developments since 2009 (C-2).

3. The EPA is not proposing to reopen or substantively modify at this time any regulations necessary for criteria pollutant and air toxic measurement and standards, CAFE testing, and associated fuel economy labeling requirements. If there are any elements of our regulations, test procedures, or GHG emission models proposed for removal that should remain to support other programs outside of the EPA's GHG standards, we are seeking comment on what those elements are and why their preservation in the CFR is necessary (C-3).

4. We seek comment on the nature and extent of any reliance interests that may have arisen from our assertion of regulatory authority over GHG emissions from new motor vehicles and engines and are committed to assessing any such interests, determining whether they are significant, and weighing such interests against competing rationales, as required by law (C-4).

5. We seek comment on whether regulated parties have any significant reliance interests in our GHG emission standards for new motor vehicles and new motor vehicle engines (C-5).

6. We seek comment on whether any reliance interests in national uniformity and preemption would support adopting certain rationales and not finalizing other rationales (C-6).

7. We seek comment on whether additional stakeholders have reliance interests in GHG emission standards for new motor vehicles and engines (C-7).

8. We seek comment on potential reliance interests in GHG emission standards for global climate change concerns under CAA section 202(a), including on whether such reliance justifies retaining such standards and the extent to which potential dangers are addressed, or could be addressed, under more specific authorities (C-8).

9. We seek comment on reliance interests in the Endangerment Finding

¹³⁸ See 49 CFR 535.8(a)(6).

and GHG emission standards issued under CAA section 202(a) and reserve the right to direct out of scope comments to the appropriate rulemaking docket for the applicable regulatory action (C–9).

10. We seek comment on the continued preemptive effect of the CAA in the event that the EPA finalizes the proposed rescission or otherwise concludes that it lacks authority to regulate GHG emissions under CAA section 202(a) or any other specific regulatory provision of the CAA (C–10).

11. We seek comment on the proposed interpretation of CAA 202(a) as discussed in section III.A.1 of this preamble, including the rationales presented in that section and any further rationales that commenters believe support, or detract from, this interpretation (C–11).

12. We seek comment on the rationale presented in section V of this preamble, including on the proper interpretation of “requisite technology,” the appropriate standard for measuring pollution prevention and control, and the scientific threshold for determining measurable impacts on trends in climate change (C–12).

13. We seek comment on the proposed bases for repeal presented in section V of this preamble, including on the economics of fleet turnover, the relative efficiency and emission reductions achieved by newer vehicles, and the potential costs to air quality of retaining standards that may slow fleet turnover as compared to the potential benefits of retaining GHG emission standards in response to global climate change concerns (C–13).

14. We seek comment on the rationales presented in section V of this preamble, including on whether such public welfare considerations can and should be considered when prescribing and revising emission standards under CAA section 202(a) (C–14).

15. We seek comment on how to give effect to the statutory language discussed in section V of this preamble as incorporated into the reference in CAA section 202(a) to effects on “public health or welfare” (C–15).

16. We request comment on all proposed changes described in section VI of this preamble, including on any additional regulatory provisions for engines and vehicles that should be removed as part of repealing the GHG standards or should be retained to effectuate unrelated standards that we are not proposing to repeal or revise (C–16).

17. NHTSA’s medium- and heavy-duty fuel efficiency regulations in 49 CFR part 535 refer to several sections in

the EPA’s 40 CFR parts 1036 and 1037 that we are proposing to modify or remove. We request comment on whether any of these provisions should be retained for the final rule with a CFR notation throughout 40 CFR parts 1036 and 1037 explaining that these sections only apply to NHTSA’s heavy-duty fuel efficiency program (C–17).

18. We request comment on the time required to transition from requiring manufacturers to supply relevant data to the EPA to requiring that they supply the data directly to NHTSA (C–18).

19. We request comment on all proposed changes described in preamble section VI, including suggestions to remove additional regulatory provisions for such engines and vehicles for purposes of GHG regulation or to retain provisions we propose to remove. Specifically, we request comment on the proposed regulatory changes for the light- and medium-duty vehicle programs under 40 CFR parts 85, 86, and 600, and whether additional changes should be considered for purposes of GHG regulation (C–19).

20. We request comment on all proposed changes described in preamble section VI, including suggestions to remove additional regulatory provisions for such engines and vehicles for purposes of GHG regulation or to retain provisions we propose to remove. Specifically, we request comment on the proposed regulatory changes for the heavy-duty engine and vehicle programs under 40 CFR parts 1036 and 1037 and whether we should consider additional changes for purposes of GHG regulation (C–20).

21. We request comment on the analysis provided within section VIII related to the benefits and costs of the proposed action and whether benefit cost analysis is an appropriate and lawful basis for repealing the Endangerment Finding and/or resulting vehicle standards (C–21).

22. The information collection activities in this proposed rule have been submitted for approval to OMB under the Paperwork Reduction Act (PRA), as described in section VIII.C of this preamble. Submit your comments on the Agency’s description of the information that would no longer be required to be provided, the accuracy of the provided burden savings estimates, and any suggested methods for minimizing respondent burden to the EPA using the docket identified at the beginning of this rule (C–22).

23. Stakeholders state that NCA5 does not meet the requirements under Executive Order 14303 and deviated from OMB guidelines on quality,

objectivity, utility, and integrity of information disseminated by Federal agencies. The Administrator takes these concerns seriously and seeks public comment on the validity of these concerns and how they should be taken into account when determining whether to finalize any of the alternatives proposed in this action (C–23).

24. We further propose that *Massachusetts* must be read together with the Supreme Court’s decisions in *West Virginia* and *UARG*, which applied the major questions doctrine to statutory provisions similar to CAA section 202(a). To that end, we seek comment on whether *Massachusetts* applied the major questions doctrine in the first instance, and, if it did, whether that analysis informs the meaning of CAA section 202(a) on its own terms and in light of *UARG* and *West Virginia* (C–24).

25. We propose that the EPA’s course of rulemaking has not been limited to emission standards as anticipated in *Massachusetts*. To that end, we seek comment on whether a new analysis is required because the EPA’s rulemakings in response to the Endangerment Finding have included electric vehicle mandates that require shifting the national vehicle fleet from one type of vehicle and vehicle fuel to another (C–25).

26. We propose that even if intervening legal developments have not foreclosed the regulation of GHG emissions from new motor vehicles and engines under CAA section 202(a), they provide a reasonable basis for the Administrator to approach the inquiry with greater caution today than was applied in the Endangerment Finding. We propose that the Administrator’s new approach requires rescinding the Endangerment Finding as fundamentally inconsistent with the framework set out in this proposed alternative. We seek comment on this alternative proposal, including on the breadth of the Administrator’s discretion to exercise judgment by rejecting the approach taken in the Endangerment Finding and the results of adopting a different approach (C–26).

27. We seek comment on any additional aspects of the Endangerment Finding that may have fallen short of the administrative law requirement that agency action be reasonable and reasonably explained. Conversely, we seek comment on why the approach taken in the Endangerment Finding remains reasonable given the legal and scientific developments discussed in this proposal, and the impact, if any, of the EPA’s denial of rulemaking petitions in 2022 and 2010 on this alternative proposal (C–27).

VIII. Statutory and Executive Order Reviews

Additional information about these statutes and Executive Orders can be found at <http://www.epa.gov/laws-regulations/laws-and-executive-orders>.

A. Executive Order 12866: Regulatory Planning and Review and Executive Order 14094: Modernizing Regulatory Review

This proposed action is an economically significant regulatory action that was submitted to the Office of Management and Budget (OMB) for review. Any changes made have been documented in the docket. The EPA has prepared a draft Regulatory Impact Analysis (RIA) for this proposed action to project impacts as required by E.O. 12866, and it can be found in the docket.¹³⁹ The EPA has not relied upon any aspect of the draft RIA as justification for this proposed rulemaking.

The EPA considered relying on our most recent RIAs from 2024 relating to GHG standards for motor vehicles¹⁴⁰ (2024 GHG Vehicle RIAs) for projecting impacts of this action. However, the 2024 GHG Vehicle RIAs significantly relied upon assumptions that we no longer believe are appropriate and that would significantly impact the costs and benefits of this proposed rule. Those

assumptions include, but are not limited to:

- 1. The impact and existence of EV-related tax credits and other subsidies from the 2022 IRA, which have been repealed in part by the 2025 OBBB and were incorporated into the RIA baseline;
 - 2. The impact of Congress' disapproval under the CRA of the EPA's waiver rule for California's Advanced Clean Truck regulation, which was incorporated into the RIA baseline but is no longer in force in California or any other State;
 - 3. Changes in consumers' interest in purchasing EVs;
 - 4. Future gasoline and diesel prices due to changes in Administration policy since 2024;
 - 5. Changes in the power generation sector as a result of recent projections for data center demands and legislative amendments in the 2025 OBBB that impact the economics of EV penetration and use; and
 - 6. Access to capital for all consumers due to differences in prices and the respective cost impacts on vehicles, given that the RIAs from 2024 assumed unlimited access to capital.
- Changes in these assumptions impact all aspects of the 2024 RIAs and, thus, the EPA cannot rely upon those assessments to confidently and appropriately quantify or monetize many of the impacts from this proposed

action. In the draft RIA for this proposal, the EPA presents estimated results from two analytical methods for projecting impacts on costs and benefits from removing the GHG standards for LD, MD and HD vehicles and HD engines.

The EPA presents five different modeled scenarios using one of the analytical methods in the draft RIA, which are summarized here in Tables 6 and 7. The first scenario contains all the same assumptions and inputs as presented in the 2024 RIAs. The second scenario estimates the impacts of removing the IRA and the California Advanced Clean Truck (ACT) rule, which the EPA included in the baseline for the 2024 RIAs assessments. Recognizing the significant uncertainties related to future gasoline and diesel prices, the third scenario considers lower fuel prices, in addition to the removal of IRA and the ACT rule. All other assumptions and inputs are the same as those used in the 2024 RIAs. The fourth and fifth scenarios build on the second and third scenarios respectively, accounting for only the first two and half years of fuel savings in estimating the net monetized impact of this proposed rule.

Table 6 and Table 7 show the net present value of the monetized savings, costs, and net savings of the five scenarios presented at 7 and 3 percent discount rates, respectively.

TABLE 6—MONETIZED SAVINGS, COSTS, AND NET SAVINGS AT 7 PERCENT NET PRESENT VALUE
[Billions of 2022 dollars]*

	2024 Light- & medium-duty vehicle multipollutant final rule (LMDV) and greenhouse gas emissions standards for heavy-duty vehicles-phase 3 (HDP3) rule analysis	2024 LMDV and HDP3 rule analysis, no IRA and ACT	2024 LMDV and HDP3 rule, no IRA and ACT; low liquid fuel prices	2024 LMDV and HDP3 rule analysis, no IRA and ACT, 2.5 years of fuel savings	2024 LMDV and HDP3 rule; no IRA and ACT, low liquid fuel prices, 2.5 years of fuel savings
Savings	\$570	\$640	\$640	\$640	\$640
Costs	590	690	420	320	260
Net Savings	(30)	(50)	220	320	380

* Results may not sum due to rounding.

TABLE 7—MONETIZED SAVINGS, COSTS AND NET SAVINGS AT 3 PERCENT NET PRESENT VALUE
[Billions of 2022 dollars]*

	2024 LMDV and HDP3 rule analysis	2024 LMDV and HDP3 rule analysis, no IRA and ACT	2024 LMDV and HDP3 rule, no IRA and ACT; low liquid fuel prices	2024 LMDV and HDP3 rule analysis; no IRA and ACT, 2.5 years of fuel savings	2024 LMDV and HDP3 rule; no IRA and ACT, low liquid fuel prices, 2.5 years of fuel savings
Savings	\$950	\$1,030	\$1,030	\$1,030	\$1,030

¹³⁹ “Reconsideration of 2009 Endangerment Finding and Greenhouse Gas vehicle Standards: Draft Regulatory Impact Analysis.” EPA–420–D–25–002. July 2025.

¹⁴⁰ See “Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles. Regulatory Impact Analysis.” EPA–420–R–24–004. March 2024;

“Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles: Phase 3. Regulatory Impact Analysis”. EPA–420–R–24–006. March 2024.

TABLE 7—MONETIZED SAVINGS, COSTS AND NET SAVINGS AT 3 PERCENT NET PRESENT VALUE—Continued
[Billions of 2022 dollars]*

	2024 LMDV and HDP3 rule analysis	2024 LMDV and HDP3 rule analysis, no IRA and ACT	2024 LMDV and HDP3 rule, no IRA and ACT; low liquid fuel prices	2024 LMDV and HDP3 rule analysis; no IRA and ACT, 2.5 years of fuel savings	2024 LMDV and HDP3 rule; no IRA and ACT, low liquid fuel prices, 2.5 years of fuel savings
Costs	1,210	1,390	870	660	550
Net Savings	(260)	(350)	160	380	490

* Results may not sum due to rounding.

The other analytical method which utilizes a revealed preference approach) can be found in the draft RIA.

The EPA requests comment on all aspects of the draft RIA, and on whether there are other approaches the EPA should consider for projecting the impacts of this proposed rule (C–20). We are requesting comment from stakeholders about what expected and modeled impacts would be from this proposal.

B. Executive Order 14192: Unleashing Prosperity Through Deregulation

This action is expected to be an Executive Order 14192 deregulatory action. A summary of the projected costs savings can be found in the draft RIA.

C. Paperwork Reduction Act (PRA)

An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for the EPA's regulations in Title 40 of the CFR are listed in 40 CFR part 9.

Submit your comments on the Agency's description of the information that would no longer be required to be provided, the accuracy of the provided burden savings estimates and any suggested methods for minimizing respondent burden to the EPA using the docket identified at the beginning of this rule. The EPA will respond to any ICR-related comments in the final rule. You may also send your ICR-related comments to OMB's Office of Information and Regulatory Affairs using the interface at www.reginfo.gov/public/do/PRAMain. Find the particular information collection by selecting "Currently under Review—Open for Public Comments" or by using the search function. OMB must receive comments no later than September 2, 2025.

The information collection activities in this proposed rule have been submitted for approval to the OMB under the PRA.

1. Light- and Medium-Duty Vehicle—2024 Final Rule

The ICR document prepared by the EPA for removal of the light- and medium-duty vehicle GHG requirements has been assigned EPA ICR 2750.03, revising EPA ICR 2750.02 (OMB 2060–0764). You can find a copy of the ICR in the docket for this rule and it is briefly summarized here.

The EPA is proposing to remove all regulations that require light- and medium-duty vehicle manufacturers to measure, report, or comply with standards for GHG emissions. Information collected to assure compliance with those requirements is no longer needed under this proposal. All other requirements covered by 2750.02 remain in effect.

Respondents/affected entities: Light- and medium-duty vehicle manufacturers, alternative fuel converters, and independent commercial importers.

Respondent's obligation to respond: This proposal relieves manufacturers of the burden to provide certain information to the EPA as part of their annual model year vehicle certification under section 208(a) of the CAA, which is required prior to entering vehicles into commerce. Participation in some programs is voluntary; but once a manufacturer has elected to participate, it must submit the required information.

Estimated number of respondents: 35 affected entities.

Frequency of response: Annually or on occasion, depending on the type of response.

Revised total estimated burden: 138,443 hours (per year) for remaining regulatory requirements covered by this ICR. Burden is defined at 5 CFR 1320.3(b).

Revised total estimated cost: \$26.3 million per year for remaining regulatory requirements covered by this ICR, which includes an estimated \$14.2 million annualized capital or operation and maintenance costs.

2. Heavy-Duty Vehicle GHG Phase 3—2024 Final Rule

The ICR document prepared by the EPA for removal of the heavy-duty GHG Phase 3 requirements has been assigned EPA ICR 2734.03, revising EPA ICR 2734.02 (OMB 2060–0753). You can find a copy of the ICR in the docket for this rule and it is briefly summarized here.

The EPA is proposing to remove all regulations that require heavy-duty motor vehicle and heavy-duty motor vehicle engine manufacturers to measure, report, or comply with the heavy-duty GHG Phase 3 standards. Information collected to assure compliance with those requirements is no longer needed under this proposal.

Respondents/affected entities: Manufacturers of heavy-duty onroad vehicles.

Respondent's obligation to respond: This proposal relieves manufacturers of the burden to provide certain information to the EPA as part of their annual model year engine and vehicle certification under section 203(a) of the CAA, which is required prior to entering vehicles into commerce.

Estimated number of respondents: 77 affected entities.

Frequency of response: Originally expected to be one-time burden; now, no requirement to report.

Revised total estimated burden: 0 hours. Burden is defined at 5 CFR 1320.03(b).

Revised total estimated cost: \$0.

3. Nonroad Compression-Ignition Engines and On-Highway Heavy Duty Engines, Supporting Statement for Information Collection Request (March 2023 Revision)

The ICR document prepared by the EPA for removal of the existing Phase 2 and earlier GHG requirements for heavy-duty engines and vehicles has been assigned EPA ICR 1684.22, revising EPA ICR 1684.21 (OMB 2060–0287). You can find a copy of the ICR in the docket for this rule and it is briefly summarized here.

The EPA is proposing to remove all regulations that require heavy-duty motor vehicle and heavy-duty motor vehicle engine manufacturers to measure, report, or comply with standards for GHG emissions. Information collected to assure compliance with those requirements is no longer needed under this proposal. All other requirements covered by EPA ICR 1684.21 remain in effect.

Respondents/affected entities:

Manufacturers of heavy-duty onroad vehicles and engines.

Respondent's obligation to respond:

This proposal relieves manufacturers of the burden to provide certain information to the EPA as part of their annual model year engine and vehicle certification under CAA section 203(a), which is required prior to entering vehicles into commerce. Participation in some programs is voluntary; but once a manufacturer has elected to participate, it must submit the required information.

Estimated number of respondents:

568 affected entities.

Frequency of response: Annually or on occasion, depending on the type of response.

Revised total estimated burden:

137,824 hours for remaining regulatory requirements covered by this ICR.

Burden is defined at 5 CFR 1320.03(b).

Revised total estimated cost: \$30.3 million for remaining regulatory requirements covered by this ICR, which includes an estimated \$17.9 million annualized capital or operation and maintenance costs.

D. Regulatory Flexibility Act (RFA)

I certify that this proposed action would not have a significant economic impact on a substantial number of small entities under the Regulatory Flexibility Act (RFA). In making this determination, the EPA concludes that the impact of concern for this rule is any significant adverse economic impact on small entities, and that the agency is certifying that this rule will not have a significant economic impact on a substantial number of small entities because the rule relieves regulatory burden on the small entities subject to the rule.

The regulated entities that are subject to the regulations we are proposing to remove in this proposed rule are engine and vehicle manufacturers, alternative fuel converters, and independent commercial importers subject to GHG emissions standards for vehicles. The Agency is certifying that this proposed action would not have a significant economic impact on a substantial number of small entities because the proposed action would relieve

regulatory burden on all entities, including all small entities, subject to the current rules. This action proposes to remove portions of the regulations of the standard-setting parts directly related to GHG emission standards and compliance provisions for implementing the EPA's GHG engine and vehicle programs. We do not anticipate that there would be any significant adverse economic impact on directly regulated small entities as a result of these revisions. We have therefore concluded that this proposed action would, if finalized, relieve regulatory burden for all directly regulated small entities. The EPA provides additional information on the RFA in Section 7 of the Draft Regulatory Impact Analysis document for this proposal.

E. Unfunded Mandates Reform Act (UMRA)

This proposed action does not contain an unfunded mandate of \$100 million (adjusted annually for inflation) or more (in 1995 dollars) as described in UMRA, 2 U.S.C. 1531–1538, and does not significantly or uniquely affect small governments. The proposed action would, if finalized, impose no enforceable duty on any state, local, or tribal governments, and would relieve duties with respect to the private sector.

F. Executive Order 13132: Federalism

This proposed action would not have federalism implications as specified in Executive Order 13132. If finalized, it would not have substantial direct effects on the states, on the relationship between the national government and the states, or on the distribution of power and responsibilities among the various levels of government.

G. Executive Order 13175: Consultation and Coordination With Indian Tribal Governments

This proposed action would not have tribal implications as specified in Executive Order 13175. If finalized, it would not have substantial direct effects on tribal governments, on the relationship between the federal government and Indian tribes, or on the distribution of power and responsibilities between the federal government and Indian tribes, as specified in Executive Order 13175. Thus, Executive Order 13175 does not apply to this proposed action.

H. Executive Order 13045: Protection of Children From Environmental Health Risks and Safety Risks

Executive Order 13045 directs federal agencies to include an evaluation of the

health and safety effects of the planned regulation on children in federal health and safety standards and explain why the regulation is preferable to potentially effective and reasonably feasible alternatives. This action is subject to Executive Order 13045 because it is a significant regulatory action under section 3(f)(1) of Executive Order 12866, and the EPA believes the environmental health or safety risks of the pollutants impacted by this action may have a disproportionate effect on children. The 2021 Policy on Children's Health also applies to this action.¹⁴¹

Although the GHG emissions at issue in this rulemaking do not have direct impacts on human health, we acknowledge the possibility that this proposal could marginally impact emissions of criteria pollutants and air toxics. Children are not expected to experience greater ambient concentrations of air pollutants than the general population. However, children are more susceptible than adults to air pollution, and children tend to spend increased time outdoors. Children make up a substantial fraction of the U.S. population, and often have unique factors that contribute to their increased risk of experiencing a health effect from exposures to ambient air pollutants because of their continuous growth and development. Children are more susceptible than adults to many air pollutants because they have (1) a developing respiratory system, (2) increased ventilation rates relative to body mass compared with adults, (3) an increased proportion of oral breathing, particularly in boys, relative to adults, and (4) behaviors that increase chances for exposure. Even before birth, the developing fetus may be exposed to air pollutants through the mother that affect development when the mother is exposed. We note that, as explained above, this proposed action would not impact separate regulatory controls for criteria pollutants or separate standards set by NHTSA. At this time, the EPA does not believe that the proposed action would have a material adverse impact on the health of individuals with respect to non-GHG air pollutants, including on children, because the EPA anticipates that the impacts of repealing GHG emission regulations would have only marginal and incidental impacts on the emission of non-GHG air pollutants. Potential health impacts of such air pollutants will continue to be controlled through direct emissions limits and a

¹⁴¹ U.S. Environmental Protection Agency. (2021). 2021 Policy on Children's Health: <https://www.epa.gov/system/files/documents/2021-10/2021-policy-on-childrens-health.pdf>.

number of other programs that target regional and national air quality, including the NAAQS program.

I. Executive Order 13211: Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use

This proposed action, which is a significant regulatory action under Executive Order 12866, would have a significant effect on the supply, distribution or use of energy. The EPA has prepared a Statement of Energy Effects for this proposed action as follows.

This action proposes to remove the GHG emission standards and related compliance provisions for light-, medium-, and heavy-duty engines and vehicles. This action would, if finalized, result in an estimated increase in the consumption of petroleum and an estimated reduction in the consumption of electricity.

J. National Technology Transfer and Advancement Act (NTTAA) and 1 CFR Part 51

This proposed action involves technical standards. However, the proposed changes to the regulation include removing GHG emission standards and the corresponding measurement and compliance procedures, some of which also involve removing existing references to voluntary consensus standards and other technical standards. This proposed action does not include any new requirements or new references to technical standards.

List of Subjects

40 CFR Part 85

Confidential business information, Greenhouse gases, Imports, Labeling, Motor vehicle pollution, Reporting and recordkeeping requirements, Research Warranties.

40 CFR Part 86

Environmental protection, Administrative practice and procedure, Confidential business information, Incorporation by reference, Labeling, Motor vehicle pollution, Reporting and recordkeeping requirements.

40 CFR Part 600

Environmental protection, Administrative practice and procedure, Electric power, Fuel economy, Greenhouse gases, Labeling, Reporting and recordkeeping requirements.

40 CFR Part 1036

Environmental protection, Administrative practice and procedure,

Air pollution control, Confidential business information, Greenhouse gases, Incorporation by reference, Labeling, Motor vehicle pollution, Reporting and recordkeeping requirements, Warranties.

40 CFR Part 1037

Environmental protection, Administrative practice and procedure, Air pollution control, Confidential business information, Incorporation by reference, Labeling, Motor vehicle pollution, Reporting and recordkeeping requirements, Warranties.

40 CFR Part 1039

Administrative practice and procedure, Air pollution control, Confidential business information, Imports, Labeling, Penalties, Reporting and recordkeeping requirements, Warranties.

Lee Zeldin,
Administrator.

For the reasons set out in the preamble, we propose to amend title 40, Chapter I of the Code of Federal Regulations as set forth below.

PART 85—CONTROL OF AIR POLLUTION FROM MOBILE SOURCES

- 1. The authority citation for part 85 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

§ 85.525 [Amended]

- 2. Amend § 85.525 by removing and reserving paragraph (b).
■ 3. Amend § 85.1515 by revising paragraph (d) to read as follows:

§ 85.1515 Emission standards and test procedures applicable to imported nonconforming motor vehicles and motor vehicle engines.

* * * * *

(d) An ICI may not certify using nonconformance penalties.

§ 85.1803 [Amended]

- 4. Amend § 85.1803 by removing paragraph (e).

§ 85.1805 [Amended]

- 5. Amend § 85.1805 by removing and reserving paragraph (b).
■ 6. Amend § 86.1902 by removing and reserving paragraph (b)(2) and revising paragraph (d). The revision reads as follows:

§ 85.1902 Definitions.

* * * * *

(d) *Voluntary emissions recall* means a repair, adjustment, or modification program voluntarily initiated and conducted by a manufacturer to remedy

any emission-related defect for which direct notification of vehicle or engine owners has been provided.

* * * * *

§ 85.2103 [Amended]

- 7. Amend § 85.2103 by removing paragraphs (d)(1)(v) and (d)(3).

PART 86—CONTROL OF EMISSIONS FROM NEW AND IN-USE HIGHWAY VEHICLES AND ENGINES

- 8. The authority citation for part 86 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

§ 86.1 [Amended]

- 9. Amend § 86.1 by removing and reserving paragraphs (c)(2) and (3) and (f)(3), (17), (21), and (22) and removing paragraph (h).
■ 10. Amend § 86.007–11 by revising paragraphs (g)(1) and (6) to read as follows:

§ 86.007–11 Emission standards and supplemental requirements for 2007 and later model year diesel heavy-duty engines and vehicles.

* * * * *

(g) * * *

(1) The engines must be of a configuration that is identical to one that is certified under 40 CFR part 1039, and must be certified with a Family Emission Limit for PM of 0.020 g/kW-hr using the same duty cycles that apply under 40 CFR part 1039.

* * * * *

(6) Engines certified under this paragraph (g) may not generate or use emission credits under this part or under 40 CFR part 1039.

* * * * *

- 11. Amend § 86.008–10 by revising paragraph (g)(6) to read as follows:

§ 86.008–10 Emission standards for 2008 and later model year Otto-cycle heavy-duty engines and vehicles.

* * * * *

(g) * * *

(6) Engines certified under this paragraph (g) may not generate or use emission credits under this part.

* * * * *

- 12. Amend § 86.1801–12 by:
■ a. Removing and reserving paragraph (a)(2)(ii)(B);
■ b. Revising paragraphs (a)(3), (b), and (i); and
■ c. Removing paragraphs (j) and (k).
The revisions read as follows:

§ 86.1801–12 Applicability.

(a) * * *

(3) The provisions of this subpart do not apply to heavy-duty vehicles above 14,000 pounds GVWR (see § 86.016–1

and 40 CFR parts 1036 and 1037), except as follows:

(i) Heavy-duty vehicles above 14,000 pounds GVWR and at or below 19,500 pounds GVWR may be optionally certified to the exhaust emission standards in this subpart if they are properly included in a test group with similar vehicles at or below 14,000 pounds GVWR. Emission standards apply to these vehicles as if they were Class 3 medium-duty vehicles.

(ii) [Reserved]

(iii) Evaporative and refueling emission standards apply for heavy-duty vehicles above 14,000 pounds GVWR as specified in 40 CFR 1037.103.

* * * * *

(b) *Relationship to 40 CFR parts 1036 and 1037.* If any heavy-duty vehicle is not subject to standards and certification requirements under this subpart, the vehicle and its installed engine are instead subject to standards and certification requirements under 40 CFR parts 1036 and 1037, as applicable. If you optionally certify engines or vehicles to standards under 40 CFR part 1036 or 40 CFR part 1037, respectively, those engines or vehicles are subject to all the regulatory requirements in 40 CFR parts 1036 and 1037 as if they were mandatory.

* * * * *

(i) *Types of pollutants.* Criteria pollutant standards apply for NO_x, NMOG, HC, formaldehyde, PM, and CO, including exhaust, evaporative, and refueling emission standards. These pollutants are sometimes described collectively as “criteria pollutants” because they are either criteria pollutants under the Clean Air Act or precursors to the criteria pollutants ozone and PM.

■ 13. Amend § 86.1803–01 by:

■ a. Removing the definitions of “AC1”, “AC2”, “Air Conditioning Idle Test”, “Base level”, “Base tire”, “Base vehicle”, “Combined CO₂”, “Combined CREE”, and “Configuration”;

■ b. Revising the definition of “Defeat device”;

■ c. Removing and reserving paragraph (1) of the definition of “Emergency vehicle”;

■ d. Revising the definition of “Engine code”;

■ e. Removing the definition of “Footprint”, “Full size pickup truck”, “Mild hybrid electric vehicle”, “Strong hybrid electric vehicle”, “Subconfiguration”, “Track width”, and “Transmission class”; and

■ f. Adding a definition of “Work factor” in alphabetical order.

The revisions and addition read as follows:

§ 86.1803–01 Definitions.

* * * * *

Defeat device means an auxiliary emission control device (AEC) that reduces the effectiveness of the emission control system under conditions which may reasonably be expected to be encountered in normal vehicle operation and use, unless:

(1) Such conditions are substantially included in driving cycles specified in this subpart or the fuel economy test procedures in 40 CFR part 600;

(2) The need for the AEC is justified in terms of protecting the vehicle against damage or accident;

(3) The AEC does not go beyond the requirements of engine starting; or

(4) The AEC applies only for emergency vehicles and the need is justified in terms of preventing the vehicle from losing speed, torque, or power due to abnormal conditions of the emission control system, or in terms of preventing such abnormal conditions from occurring, during operation related to emergency response. Examples of such abnormal conditions may include excessive exhaust backpressure from an overloaded particulate trap, and running out of diesel exhaust fluid for engines that rely on urea-based selective catalytic reduction.

* * * * *

Engine code means a unique combination within a test group of displacement, fuel injection (or carburetor) calibration, choke calibration, distributor calibration, auxiliary emission control devices, and other engine and emission control system components specified by the Administrator. For electric vehicles, engine code means a unique combination of manufacturer, electric traction motor, motor configuration, motor controller, and energy storage device.*

* * * * *

Work factor, WF, means the characteristic value representing a vehicle’s work potential, calculated to the nearest pound using the following equation:

$$WF = 0.75 \times (GVWR - \text{Curb Weight} + xwd) + 0.25 \times (GCWR - GVWR)$$

Where:

xwd = 500 pounds if the vehicle has four-wheel drive or all-wheel drive; *xwd* = 0 pounds for all other vehicles.

* * * * *

■ 14. Amend § 86.1805–12 by revising paragraph (a) to read as follows:

§ 86.1805–12 Useful life.

(a) Except as permitted under paragraph (b) of this section or required under paragraphs (c) and (d) of this

section, the full useful life for all LDVs and LLDTs is a period of use of 10 years or 120,000 miles, whichever occurs first. The full useful life for all HLDTs, MDPVs, and complete heavy-duty vehicles is a period of 11 years or 120,000 miles, whichever occurs first. These full useful life values apply to all exhaust, evaporative and refueling emission requirements except for standards which are specified to only be applicable at the time of certification.

* * * * *

■ 15. Revise § 86.1805–17 to read as follows:

§ 86.1805–17 Useful life.

(a) *General provisions.* The useful life values specified in this section apply for all exhaust, evaporative, refueling, and OBD emission requirements described in this subpart, except for standards that are specified to apply only at certification. Useful life values are specified as a given number of calendar years or miles of driving, whichever comes first.

(b) [Reserved]

(c) *Cold temperature emission standards.* The cold temperature NMHC emission standards in § 86.1811–17 apply for a useful life of 10 years or 120,000 miles for LDV and LLDT, and 11 years or 120,000 miles for HLDT and HDV. The cold temperature CO emission standards in § 86.1811–17 apply for a useful life of 5 years or 50,000 miles.

(d) *Criteria pollutants.* The useful life provisions of this paragraph (d) apply for all emission standards not covered by paragraph (c) of this section. This paragraph (d) applies for the cold temperature emission standards in § 86.1811–27(c). Except as specified in paragraph (f) of this section and in § 86.1811, 86.1813, and 86.1816, the useful life for LDT2, HLDT, MDPV, and HDV is 15 years or 150,000 miles. The useful life for LDV and LDT1 is 10 years or 120,000 miles. Manufacturers may optionally certify LDV and LDT1 to a useful life of 15 years or 150,000 miles, in which case the longer useful life would apply for all the standards and requirements covered by this paragraph (d).

(e) *Intermediate useful life.* Where exhaust emission standards are specified for an intermediate useful life, these standards apply for five years or 50,000 miles.

§ 86.1807–01 [Amended]

■ 16. Amend § 86.1807–01 by removing and reserving paragraph (a)(3)(iv).

■ 17. Amend § 86.1809–12 by revising paragraph (d)(1) to read as follows:

§ 86.1809–12 Prohibition of defeat devices.

* * * *

(d) * * *

(1) The manufacturer must show to EPA's satisfaction that the vehicle design does not incorporate strategies that unnecessarily reduce emission control effectiveness exhibited over the driving cycles specified in this subpart or the fuel economy test procedures in 40 CFR part 600 when the vehicle is operated under conditions that may reasonably be expected to be encountered in normal operation and use.

* * * *

■ 18. Amend § 86.1810–09 by revising paragraph (f)(2) to read as follows:

§ 86.1810–09 General standards; increase in emissions; unsafe condition; waivers.

* * * *

(f) * * *

(2) For vehicles that comply with the cold temperature NMHC standards described in § 86.1811–10(g), manufacturers must submit an engineering evaluation indicating that common calibration approaches are utilized at high altitudes (except when there are specific high altitude calibration needs to deviate from low altitude emission control practices). Any deviation from low altitude emission control practices must be included in the auxiliary emission control device (AECDD) descriptions submitted at certification. Any AECDD specific to high altitude must require engineering emission data for EPA evaluation to quantify any emission impact and validity of the AECDD.

* * * *

■ 19. Amend § 86.1810–17 by revising paragraph (j) to read as follows:

§ 86.1810–17 General requirements.

* * * *

(j) Small-volume manufacturers that modify a vehicle already certified by a different company may recertify that vehicle under this subpart S based on the vehicle supplier's compliance with fleet average standards for criteria exhaust emissions and evaporative emissions as follows:

(1) The recertifying manufacturer must certify the vehicle at bin levels and family emission limits that are the same as or more stringent than the corresponding bin levels and family emission limits for the vehicle supplier.

(2) The recertifying manufacturer must meet all the standards and requirements described in this subpart S, except for the fleet average standards for criteria exhaust emissions and evaporative emissions.

(3) The vehicle supplier must send the small-volume manufacturer a written statement accepting responsibility to include the subject vehicles in the vehicle supplier's exhaust and evaporative fleet average calculations in §§ 86.1860–17 and 86.1864–10.

(4) The small-volume manufacturer must describe in the application for certification how the two companies are working together to demonstrate compliance for the subject vehicles. The application must include the statement from the vehicle supplier described in paragraph (j)(3) of this section.

(5) The vehicle supplier must include a statement that the vehicle supplier is including the small volume manufacturer's sales volume and emissions levels in the vehicle supplier's fleet average reports under §§ 86.1860–17 and 86.1864–10.

* * * *

■ 20. Amend § 86.1805–12 by revising paragraph (a) to read as follows:

§ 86.1811–17 Exhaust emission standards for light-duty vehicles, light-duty trucks and medium-duty passenger vehicles.

(a) *Applicability and general provisions.* This section describes exhaust emission standards that apply for model year 2017 and later light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles. MDPVs are subject to all the same emission standards and certification provisions that apply to LDT4. Some of the provisions of this section also apply to heavy-duty vehicles as specified in § 86.1816. See § 86.1813 for evaporative and refueling emission standards. This section may apply to vehicles from model years earlier than 2017 as specified in paragraph (b)(11) of this section.

* * * *

§ 86.1811–27 [Amended]

■ 21. Amend § 86.1811–27 by removing paragraph (a)(4).

§ 86.1815–27 [Removed]

■ 22. Remove § 86.1815–27.

■ 23. Amend § 86.1816–18 by revising paragraph (a) to read as follows:

§ 86.1816–18 Emission standards for heavy-duty vehicles.

(a) *Applicability and general provisions.* This section describes Tier 3 exhaust emission standards for complete heavy-duty vehicles. These standards are optional for incomplete heavy-duty vehicles and for heavy-duty vehicles above 14,000 pounds GVWR as described in § 86.1801. See § 86.1813 for evaporative and refueling emission

standards. This section starts to apply in model year 2018, except that the provisions may apply to vehicles before model year 2018 as specified in paragraph (b)(11) of this section. This section applies for model year 2027 and later vehicles only as specified in § 86.1811–27. Separate requirements apply for MDPV as specified in § 86.1811. See subpart A of this part for requirements that apply for incomplete heavy-duty vehicles and for heavy-duty engines certified independent of the chassis. The following general provisions apply:

(1) Test all vehicles as described in this section using a chassis dynamometer; establish appropriate load settings based on adjusted loaded vehicle weight (see § 86.1803).

(2) Some provisions apply differently depending on the vehicle's power-to-weight ratio. Determine a vehicle's power-to-weight ratio by dividing the engine's rated power by the vehicle's GVWR (in hp/pound). For purposes of this section, if a test group includes multiple vehicle configurations, use the vehicle with the highest power-to-weight ratio to characterize the test group.

(3) Use E10 test fuel as required in § 86.113, except as specified in this section.

(4) Measure emissions from hybrid electric vehicles (including plug-in hybrid electric vehicles) as described in 40 CFR part 1066, subpart F, except that these procedures do not apply for plug-in hybrid electric vehicles during charge-depleting operation.

* * * *

§ 86.1818–12 and 86.1819–14 [Removed]

■ 24. Remove §§ 86.1818–12 and 86.1819–14.

■ 25. Amend § 86.1822–01 by revising paragraph (b) to read as follows:

§ 86.1822–01 Durability data vehicle selection.

* * * *

(b) The manufacturer may select, using good engineering judgment, an equivalent or worst-case vehicle configuration in lieu of testing the vehicle selected in paragraph (a) of this section. Carryover data satisfying the provisions of § 86.1839–01 may also be used in lieu of testing the vehicle configuration selected in paragraph (a) of this section.

§ 86.1823–08 [Amended]

■ 26. Amend § 86.1823–08 by removing and reserving paragraph (m).

■ 27. Amend § 86.1827–01 by revising paragraph (a)(5) to read as follows:

§ 86.1827–01 Test group determination.

* * * *

(a) * * *

(5) Subject to the same emission standards, or FEL in the case of cold temperature NMHC or NMOG+NO_x standards, except that a manufacturer may request to group vehicles into the same test group as vehicles subject to more stringent standards, so long as all the vehicles within the test group are certified to the most stringent standards applicable to any vehicle within that test group. For example, manufacturers may include medium-duty vehicles at or below 22,000 pounds GCWR in the same test group with medium-duty vehicles above 22,000 pounds GCWR, but all vehicles included in the test group are then subject to the off-cycle emission standards and testing requirements described in § 86.1811–27(e). Light-duty trucks and light-duty vehicles may be included in the same test group if all vehicles in the test group are subject to the same criteria exhaust emission standards.

* * * *

■ 28. Amend § 86.1828–01 by revising paragraph (e) to read as follows:

§ 86.1828–01 Emission data vehicle selection.

* * * *

(e) *Alternative vehicle configurations.* The manufacturer may use good engineering judgment to select an equivalent or worst-case vehicle configuration in lieu of testing the vehicle selected in paragraphs (a) through (c) of this section. Carryover data satisfying the provisions of § 86.1839 may also be used in lieu of testing the vehicle configuration selected in paragraphs (a) through (c) of this section.

* * * *

■ 29. Amend § 86.1829–15 by:

- a. Revising paragraph (d)(3);
- b. Removing and reserving paragraph (d)(6); and
- c. Revising paragraph (d)(8).

The revisions read as follows:

§ 86.1829–15 Durability and emission testing requirements; waivers.

* * * *

(d) * * *

(3) Manufacturers may omit PM measurements for fuel economy testing conducted in addition to the testing needed to demonstrate compliance with the PM emission standards.

* * * *

(8) Manufacturers may provide a statement in the application for certification that medium-duty vehicles above 22,000 pounds GCWR comply with the off-cycle emission standards in

§ 86.1811–27(e) for all normal operation and use when tested as specified. Describe in the application for certification under § 86.1844–01(d)(8) any relevant testing, engineering analysis, or other information in sufficient detail to support the statement. We may direct you to include emission measurements representing typical engine in-use operation at a range of ambient conditions. For example, we may specify certain transient and steady-state engine operation that is typical for your vehicles. Also describe the procedure you used to determine a reference brake-specific CO₂ emission rate, e_{CO_2FTP} , under § 86.1845–04(h)(6).

* * * *

■ 30. Amend § 86.1831–01 by revising paragraphs (a)(3) and (c)(2) to read as follows:

§ 86.1830–01 Acceptance of vehicles for emission testing.

(a) * * *

(3) Test vehicles must have air conditioning installed and operational if that vehicle configuration is available with air conditioning. Optional equipment must be installed or represented on test vehicles according to the provisions of § 86.1832–01.

* * * *

(c) * * *

(2) Within a durability group, the manufacturer may alter any emission data vehicle (or other vehicles such as current or previous model year emission data vehicles, running change vehicles, fuel economy data vehicles, and development vehicles) in lieu of building a new test vehicle providing that the modification will not impact the representativeness of the vehicle's test results. Manufacturers shall use good engineering judgment in making such determinations. Development vehicles which were used to develop the calibration selected for emission data testing may not be used as the EDV for that vehicle configuration. Vehicles from outside the durability group may be altered with advance approval of the Administrator.

* * * *

■ 31. Amend § 86.1835–01 by revising paragraphs (a)(4), (b)(3), and (c) to read as follows:

§ 86.1835–01 Confirmatory certification testing.

(a) * * *

(4) Retesting for fuel economy may be conducted under the provisions of 40 CFR 600.008–08.

(b) * * *

(3) For light-duty vehicles, light-duty trucks, and medium-duty passenger

vehicles the manufacturer shall conduct a retest of the FTP or highway test if the difference between the fuel economy of the confirmatory test and the original manufacturer's test equals or exceeds three percent (or such lower percentage to be applied consistently to all manufacturer conducted confirmatory testing as requested by the manufacturer and approved by the Administrator).

(i) For use in the fuel economy program described in 40 CFR part 600, the manufacturer may, in lieu of conducting a retest, accept as official the lower of the original and confirmatory test fuel economy results.

(ii) The manufacturer shall conduct a second retest of the FTP or highway test if the fuel economy difference between the second confirmatory test and the original manufacturer test equals or exceeds three percent (or such lower percentage as requested by the manufacturer and approved by the Administrator) and the fuel economy difference between the second confirmatory test and the first confirmatory test equals or exceeds three percent (or such lower percentage as requested by the manufacturer and approved by the Administrator). In lieu of conducting a second retest, the manufacturer may accept as official (for use in the fuel economy program) the lowest fuel economy of the original test, the first confirmatory test, and the second confirmatory test fuel economy results.

(c) *Official test determination.* (1) Whenever the Administrator or the manufacturer conducts a confirmatory test segment on a test vehicle, the results of that test segment, unless subsequently invalidated by the Administrator, shall comprise the official data for that test segment for the vehicle at the prescribed test point and the manufacturer's original test data for that test segment for that prescribed test point shall not be used in determining compliance with emission standards.

(i) If the Administrator or the manufacturer conducts more than one passing, valid, confirmatory test, the results from the first passing, valid confirmatory test shall be considered official and used in determining compliance with emission standards.

(ii) Official test results for fuel economy are determined in accordance with the provisions of § 600.008–08 of this chapter.

(iii) The Administrator may stop a test after any evaporative test segment and use as official data any valid results obtained up to that point in the test, as described in subpart B of this part.

(2) Whenever the Administrator or the manufacturer does not conduct a

confirmatory test on a test vehicle at a test point, the manufacturer's original test data will be accepted as the official data for that point.

(i) If the Administrator makes a determination based on testing under paragraph (a) of this section (or other appropriate correlation test data), that there is a lack of correlation between the manufacturer's test equipment or procedures and the test equipment or procedures used by the Administrator, no manufacturer's test data will be accepted for purposes of certification until the reasons for the lack of correlation are determined and the validity of the data is established by the manufacturer.

(ii) If the Administrator has reasonable basis to believe that any test data submitted by the manufacturer is not accurate or has been obtained in violation of any provisions of this subpart, the Administrator may refuse to accept that data as the official data pending retesting or submission of further information.

(iii) If the manufacturer conducts more than one test on an emission data vehicle in the same vehicle configuration (excluding confirmatory tests run under paragraph (b) of this section), the data from the last test in that series of tests on that vehicle, will constitute the official data.

* * * * *

§ 86.1838–01 [Amended]

■ 32. Amend § 86.1838–01 by removing and reserving paragraph (b)(1)(i)(B).

■ 33. Revise § 86.1839–01 to read as follows:

§ 86.1839–01 Carryover of certification and battery monitoring data.

(a) In lieu of testing an emission-data or durability vehicle selected under § 86.1822, § 86.1828, or § 86.1829, and submitting data therefrom, a manufacturer may submit exhaust emission data, evaporative emission data and/or refueling emission data, as applicable, on a similar vehicle for which certification has been obtained or for which all applicable data required under § 86.1845 has previously been submitted. To be eligible for this provision, the manufacturer must use good engineering judgment and meet the following criteria:

(1) In the case of durability data, the manufacturer must determine that the previously generated durability data represent a worst case or equivalent rate of deterioration for all applicable emission constituents compared to the vehicle configuration selected for durability demonstration. Prior to certification, the Administrator may

require the manufacturer to provide data showing that the distribution of catalyst temperatures of the selected durability vehicle configuration is effectively equivalent or lower than the distribution of catalyst temperatures of the vehicle configuration which is the source of the previously generated data.

(2) In the case of emission data, the manufacturer must determine that the previously generated emissions data represent a worst case or equivalent level of emissions for all applicable emission constituents compared to the vehicle configuration selected for emission compliance demonstration.

(b) In lieu of using newly aged hardware on an EDV as allowed under the provisions of § 86.1823–08(f)(2), a manufacturer may use similar hardware aged for an EDV previously submitted, provided that the manufacturer determines that the previously aged hardware represents a worst case or equivalent rate of deterioration for all applicable emission constituents for durability demonstration.

§ 86.1841–01 [Amended]

■ 34. Amend § 86.1841–01 by removing and reserving paragraph (a)(3).

■ 35. Amend § 86.1844–01 by:

■ a. Removing and reserving paragraph (d)(7)(iv);

■ b. Revising paragraph (d)(15);

■ c. Removing and reserving paragraph (d)(20); and

■ d. Revising paragraphs (e)(1) and (3).

The revisions read as follows:

§ 86.1844–01 Information requirements: Application for certification and submittal of information upon request.

* * * * *

(d) * * *

(15) For vehicles with fuel-fired heaters, describe the control system logic of the fuel-fired heater, including an evaluation of the conditions under which it can be operated and an evaluation of the possible operational modes and conditions under which evaporative emissions can exist. Use good engineering judgment to establish an estimated exhaust emission rate from the fuel-fired heater in grams per mile for each pollutant subject to a fleet average standard. Adjust fleet average compliance calculations in §§ 86.1861 and 86.1864 as appropriate to account for emissions from fuel-fired heaters. Describe the testing used to establish the exhaust emission rate.

* * * * *

(e) * * *

(1) Identify all emission-related components. Also identify software, AECDs, and other elements of design that are used to control exhaust or

evaporative/refueling emissions.

Identify the emission-related components by part number. Identify software by part number or other convention, as appropriate. Organize part numbers by engine code or other similar classification scheme.

* * * * *

(3) Identification and description of all vehicles covered by each certificate of conformity to be produced and sold within the U.S. The description must be sufficient to identify whether any given in-use vehicle is, or is not, covered by a given certificate of conformity, the test group and the evaporative/refueling family to which it belongs and the standards that are applicable to it, by matching readily observable vehicle characteristics and information given in the emission control information label (and other permanently attached labels) to indicators in the Part 1 Application. For example, the description must include any components or features that contribute to measured or demonstrated control of emissions for meeting exhaust or evaporative/refueling standards under this subpart. In addition, the description must be sufficient to determine for each vehicle covered by the certificate, all appropriate test parameters and any special test procedures necessary to conduct an official certification exhaust or evaporative emission test as was required by this subpart to demonstrate compliance with applicable emission standards. The description shall include, but is not limited to, information such as model name, vehicle classification (light-duty vehicle, light-duty truck, or complete heavy-duty vehicle), sales area, engine displacement, engine code, transmission type, tire size and parameters necessary to conduct exhaust emission tests such as equivalent test weight, curb and gross vehicle weight, test horsepower (with and without air conditioning adjustment), coast down time, shift schedules, cooling fan configuration, etc. and evaporative tests such as canister working capacity, canister bed volume, and fuel temperature profile. Actual values must be provided for all parameters.

* * * * *

■ 36. Amend § 86.1845–04 by:

■ a. Revising paragraphs (b)(5)(i) and (c)(5)(i);

■ b. Removing and reserving paragraph (g); and

■ d. Revising paragraph (h)(6).

The revisions read as follows:

§ 86.1845–04 Manufacturer in-use verification testing requirements.

* * * * *

(b) * * *

(5) *Testing.* (i) Each test vehicle of a test group shall be tested in accordance with the FTP and the US06 as described in subpart B of this part, when such test vehicle is tested for compliance with applicable exhaust emission standards under this subpart.

* * * * *

(c) * * *

(5) *Testing.* (i) Each test vehicle shall be tested in accordance with the FTP and the US06 as described in subpart B of this part when such test vehicle is tested for compliance with applicable exhaust emission standards under this subpart. One test vehicle from each test

group shall be tested over the FTP at high altitude. The test vehicle tested at high altitude is not required to be one of the same test vehicles tested at low altitude. The test vehicle tested at high altitude is counted when determining the compliance with the requirements shown in Table S04–06 and Table S04–07 (tables 1 and 2 to paragraph (b)(3) of this section) or the expanded sample size as provided for in this paragraph (c).

* * * * *

(h) * * *

(6) Determine a reference CO₂ emission rate, e_{CO2FTP} , as described in

40 CFR 1036.235(b) or based on measured values from any chassis FTP driving cycles under 40 CFR part 1066, subpart I, that is used for reporting data from an emission data vehicle or a fuel economy data vehicle, as follows:

Equation 1 to Paragraph (h)(6)

$$e_{CO2FTP} = \frac{m_{CO2FTP}}{W_{FTP}}$$

Where:

m_{CO2FTP} = CO₂ emission mass in grams emitted over the FTP driving cycle.

d_{FTP} = measured driving distance in miles.

W_{FTP} = work performed over the FTP.

$$W_{FTP} = \sum_{i=1}^N f_{ni} \cdot T_i \cdot \Delta t$$

i = an indexing variable that represents a 1 Hz OBD time counter over the course of the FTP drive.

N = total number of measurements over the FTP duty cycle = 1874.

f_n = engine speed for each point, i , starting from the start of the FTP drive at $i = 1$, collected from OBD PID \$0C.

T = engine torque in N·m for each point, i , starting from $i = 1$. Calculate T by subtracting Friction Torque (PID \$8E) from Indicated Torque (PID \$62) (both PIDs are percentages) and then multiplying by the reference torque (PID \$63). Set torque to zero if friction torque is greater than indicated torque.

$\Delta t = 1/f_{\text{record}}$.

f_{record} = the data recording frequency.

Example

$m_{CO2FTP} = 10,961$ g

$N = 1874$

$f_1 = 687.3$ r/min = 71.97 rad/s

$f_2 = 689.7$ r/min = 72.23 rad/s

$T_1 = 37.1$ ft·lbf = 50.3 N·m

$T_2 = 37.2$ ft·lbf = 50.4 N·m

$f_{\text{record}} = 1$ Hz

$\Delta t = 1/1 = 1$ s = 0.000277 hr

$W_{FTP} = 71.97 \cdot 50.3 \cdot 1.0 + 72.23 \cdot 50.4 \cdot 1.0 + \dots + f_{n1874} \cdot T_{1874} \cdot \Delta t_{1874}$

$W_{FTP} = 53,958,852$ W·s = 20.1 hp·hr

$$e_{CO2FTP} = \frac{10,961}{20.1}$$

$e_{CO2FTP} = 545.3$ g/hp·hr

* * * * *

■ 37. Amend § 86.1846–01 by:

■ a. Revising paragraph (a); and

■ b. Removing and reserving paragraph (b)(2).

The revision read as follows:

§ 86.1846–01 Manufacturer in-use confirmatory testing requirements.

(a) *General requirements.*

(1) Manufacturers must test, or cause testing to be conducted, under this section when the emission levels shown by a test group sample from testing under § 86.1845 exceeds the criteria specified in paragraph (b) of this section. The testing required under this section applies separately to each test group and at each test point (low and high mileage) that meets the specified criteria. The testing requirements apply separately for each model year.

(2) The provisions of § 86.1845–04(a)(3) regarding fuel sulfur effects apply equally to testing under this section.

* * * * *

§ 86.1848–10 [Amended]

■ 38. Amend § 86.1848–10 by removing and reserving paragraph (c)(9).

■ 39. Amend § 86.1854–12 by revising paragraph (a)(2)(iv) to read as follows:

§ 86.1854–12 Prohibited acts.

(a) * * *

(2) * * *

(iv) For a person to fail to establish or maintain records as required under §§ 86.1844, 86.1862, and 86.1864 with regard to vehicles.

* * * * *

■ 40. Revise and republish § 86.1861–17 to read as follows:

§ 86.1861–17 How do the NMOG + NO_x and evaporative emission credit programs work?

You may use emission credits for purposes of certification to show compliance with the applicable fleet average NMOG+NO_x standards from § 86.1811 and 86.1816 and the fleet average evaporative emission standards from § 86.1813 as described in 40 CFR part 1036, subpart H, with certain exceptions and clarifications as specified in this section. MDPVs are subject to the same provisions of this section that apply to LDT4.

(a) Calculate emission credits as described in this paragraph (a) instead of using the provisions of 40 CFR 1036.705. Calculate positive or negative emission credits relative to the applicable fleet average standard. Calculate positive emission credits if your fleet average level is below the standard. Calculate negative emission credits if your fleet average value is above the standard. Calculate credits separately for each applicable fleet average standard and calculate total credits for each averaging set as specified in paragraph (b) of this section. Convert units from mg/mile to g/mile as needed for performing calculations. Calculate emission credits using the following equation, rounded to the nearest whole number:

Equation 1 to Paragraph (a)

$$\text{Emission credit} = \text{Volume} \cdot [\text{Fleet average standard} - \text{Fleet average value}]$$

Where:

Emission credit = The positive or negative credit for each discrete fleet average standard, in units of vehicle-grams per mile for NMOG+NO_x and vehicle-grams per test for evaporative emissions.

Volume = Sales volume in a given model year from the collection of test groups or evaporative families covered by the fleet average value, as described in § 86.1860.

(b) The following restrictions apply instead of those specified in 40 CFR 1036.740:

(1) Except as specified in paragraph (b)(2) of this section, emission credits may be exchanged only within an averaging set, as follows:

(i) HDV represent a separate averaging set with respect to all emission standards.

(ii) Except as specified in paragraph (b)(1)(iii) of this section, light-duty program vehicles represent a single averaging set with respect to all emission standards. Note that FTP and SFTP credits for Tier 3 vehicles are not interchangeable.

(iii) LDV and LDT1 certified to standards based on a useful life of 120,000 miles and 10 years together represent a single averaging set with respect to NMOG+NO_x emission standards. Note that FTP and SFTP credits for Tier 3 vehicles are not interchangeable.

(iv) The following separate averaging sets apply for evaporative emission standards:

(A) LDV and LDT1 together represent a single averaging set.

(B) LDT2 represents a single averaging set.

(C) HLDT represents a single averaging set.

(D) HDV represents a single averaging set.

(2) You may exchange evaporative emission credits across averaging sets as follows if you need additional credits to offset a deficit after the final year of maintaining deficit credits as allowed under paragraph (c) of this section:

(i) You may exchange LDV/LDT1 and LDT2 emission credits.

(ii) You may exchange HLDT and HDV emission credits.

(3) Except as specified in paragraph (b)(4) of this section, credits expire after five years. For example, credits you

generate in model year 2018 may be used only through model year 2023.

(4) For the Tier 3 declining fleet average FTP and SFTP emission standards for NMOG+NO_x described in § 86.1811–17(b)(8), credits generated in model years 2017 through 2024 expire after eight years, or after model year 2030, whichever comes first; however, these credits may not be traded after five years. This extended credit life also applies for small-volume manufacturers generating credits under § 86.1811–17(h)(1) in model years 2022 through 2024. Note that the longer credit life does not apply for heavy-duty vehicles, for vehicles certified under the alternate phase-in described in § 86.1811–17(b)(9), or for vehicles generating early Tier 3 credits under § 86.1811–17(b)(11) in model year 2017.

(5) Tier 3 credits for NMOG+NO_x may be used to demonstrate compliance with Tier 4 standards without adjustment, except as specified in § 86.1811–27(b)(6)(ii).

(6) A manufacturer may generate NMOG+NO_x credits from model year 2027 through 2032 electric vehicles that qualify as MDPV and use those credits for certifying medium-duty vehicles, as follows:

(i) Calculate generated credits separately for qualifying vehicles. Calculate generated credits by multiplying the applicable standard for light-duty program vehicles by the sales volume of qualifying vehicles in a given model year.

(ii) Apply generated credits to eliminate any deficit for light-duty program vehicles before using them to certify medium-duty vehicles.

(iii) Apply the credit provisions of this section as specified, except that you may not buy or sell credits generated under this paragraph (b)(6).

(iv) Describe in annual credit reports how you are generating certain credit quantities under this paragraph (b)(6). Also describe in your end of year credit report how you will use those credits for certifying light-duty program vehicles or medium-duty vehicles in a given model year.

(c) The credit-deficit provisions 40 CFR 1036.745 apply to the NMOG+NO_x and evaporative emission standards for

Tier 3 and Tier 4 vehicles. Credit-deficit provisions are not affected by the transition from Tier 3 to Tier 4 standards.

(d) The reporting and recordkeeping provisions of § 86.1862 apply instead of those specified in 40 CFR 1036.730 and 1036.735.

(e) The provisions of 40 CFR 1036.625 do not apply.

§ 86.1865–12, 86.1866–12, 86.1867–12, and 86.1867–31 [Removed]

■ 41. Remove §§ 86.1865–12, 86.1866–12, 86.1867–12, and 86.1867–31.

■ 42. Amend § 86.1868–12 by:

■ a. Revising the introductory text and paragraph (c);

■ b. Removing and reserving paragraph (d); and

■ c. Revising paragraphs (g) introductory text and (g)(3) introductory text.

to read as follows:

§ 86.1868–12 CO₂ credits for improving the efficiency of air conditioning systems.

The regulation at 40 CFR 600.510 describes how manufacturers may calculate fuel consumption improvement values based on improvements to air conditioning efficiency. This section describes how to calculate credits to determine the average fuel economy for comparing to the Corporate Average Fuel Economy standard. The provisions of this section do not apply for medium-duty vehicles. Credits shall be calculated according to this section for each air conditioning system that the manufacturer is using to generate credits. Manufacturers must validate credits under this section based on testing as described in paragraph (g) of this section. Starting in model year 2027, manufacturers may generate credits under this section only for vehicles propelled by internal combustion engines.

* * * * *

(c) The total efficiency credits generated by an air conditioning system shall be calculated in megagrams separately for passenger automobiles and light trucks according to the following formula:

Equation 1 to Paragraph (c)

$$\text{Total Credits} = \frac{\text{Credit} \cdot \text{Production} \cdot \text{VLM}}{1,000,000}$$

Where:

Credit = the air conditioning efficiency credit in grams per mile determined in

paragraph (b) of this section. Starting in

model year 2027, multiply the credit value for PHEV by (1-UF), where UF = the fleet utility factor established under 40 CFR 600.116-12(c)(1) or (c)(10)(iii) (weighted 55 percent city, 45 percent highway).

Production = The total number of passenger automobiles or light trucks, whichever is applicable, produced with the air conditioning system to which the efficiency credit value from paragraph (b) of this section applies.

VLM = vehicle lifetime miles, which for passenger automobiles shall be 195,264 and for light trucks shall be 225,865.

* * * * *

(g) For AC17 validation testing and reporting requirements, manufacturers must validate air conditioning efficiency credits by using the AC17 Test Procedure in 40 CFR 1066.845 as follows:

* * * * *

(3) For the first model year for which an air conditioning system is expected to generate credits, the manufacturer must select for testing the projected highest-selling vehicle configuration within each combination of vehicle platform and air conditioning system (as those terms are defined in § 86.1803). The manufacturer must test at least one unique air conditioning system within each vehicle platform in a model year, unless all unique air conditioning systems within a vehicle platform have been previously tested. A unique air conditioning system design is a system with unique or substantially different component designs or types and/or system control strategies (e.g., fixed-displacement vs. variable displacement compressors, orifice tube vs. thermostatic expansion valve, single vs. dual evaporator, etc.). In the first year of such testing, the tested vehicle configuration shall be the highest production vehicle configuration within each platform. In subsequent model years the manufacturer must test other unique air conditioning systems within the vehicle platform, proceeding from the highest production untested system until all unique air conditioning systems within the platform have been tested, or until the vehicle platform experiences a major redesign. Whenever a new unique air conditioning system is tested, the highest production vehicle configuration using that system shall be the vehicle selected for testing. Credits may continue to be generated by the air conditioning system installed in a vehicle platform provided that:

* * * * *

■ 43. Amend § 86.1869-12 by revising the introductory text and paragraphs (a), (b)(1) introductory text, (b)(2) introductory text, (b)(2)(v), (c)

introductory text, and (e)(2)(i) to read as follows:

§ 86.1869-12 CO₂ credits for off-cycle CO₂ reducing technologies.

The regulation at 40 CFR 600.510 describes how manufacturers may calculate fuel consumption improvement values based on vehicle improvements that are not reflected in testing to demonstrate compliance with exhaust emission standards. This section describes how to calculate credits to determine the average fuel economy for comparing to the Corporate Average Fuel Economy standard through model year 2032. The provisions of this section do not apply for medium-duty vehicles. Manufacturers may no longer generate credits under this section starting in model year 2027 for vehicles deemed to have zero tailpipe emissions and in model year 2033 for all other vehicles. Manufacturers may no longer generate credits under paragraphs (c) and (d) of this section for any type of vehicle starting in model year 2027.

(a) Manufacturers may generate credits for CO₂-reducing technologies where the CO₂ reduction benefit of the technology is not adequately captured on the Federal Test Procedure and/or the Highway Fuel Economy Test such that the technology would not be otherwise installed for purposes of meeting Corporate Average Fuel Economy standards. These technologies must have a measurable, demonstrable, and verifiable real-world CO₂ reduction that occurs outside the conditions of the Federal Test Procedure and the Highway Fuel Economy Test. These optional credits are referred to as “off-cycle” credits. The technologies must not be integral or inherent to the basic vehicle design, such as engine, transmission, mass reduction, passive aerodynamic design, and tire technologies. Technologies installed for non-off-cycle emissions related reasons are also not eligible as they would be considered part of the baseline vehicle design. The technology must not be inherent to the design of occupant comfort and entertainment features except for technologies related to reducing passenger air conditioning demand and improving air conditioning system efficiency. Notwithstanding the provisions of this paragraph (a), off-cycle menu technologies included in paragraph (b) of this section remain eligible for credits. Off-cycle technologies used to generate emission credits are considered emission-related components subject to applicable requirements and must be demonstrated to be effective for the full useful life of

the vehicle. Unless the manufacturer demonstrates that the technology is not subject to in-use deterioration, the manufacturer must account for the deterioration in their analysis. Durability evaluations of off-cycle technologies may occur at any time throughout a model year, provided that the results can be factored into the data provided in the model year report. Off-cycle credits may not be approved for crash-avoidance technologies, safety critical systems or systems affecting safety-critical functions, or technologies designed for the purpose of reducing the frequency of vehicle crashes. Off-cycle credits may not be earned for technologies installed on a motor vehicle to attain compliance with any vehicle safety standard or any regulation set forth in Title 49 of the Code of Federal Regulations. The manufacturer must use one of the three options specified in this section to establish off-cycle credits under this section.

(b) * * *

(1) The manufacturer may generate off-cycle credits for certain technologies as specified in this paragraph (b)(1). Technology definitions are in paragraph (b)(4) of this section. Calculated credit values shall be rounded to the nearest 0.1 grams/mile.

* * * * *

(2) The maximum allowable off-cycle credit for the combined passenger automobile and light truck fleet attributable to use of the default credit values in paragraph (b)(1) of this section is specified in paragraph (b)(2)(v) of this section. If the total of the off-cycle credit values from paragraph (b)(1) of this section does not exceed the specified off-cycle credit cap for any passenger automobile or light truck in a manufacturer's fleet, then the total off-cycle credits may be calculated according to paragraph (f) of this section. If the total of the off-cycle credit values from paragraph (b)(1) of this section exceeds the specified off-cycle credit cap for any passenger automobile or light truck in a manufacturer's fleet, then the gram per mile decrease for the combined passenger automobile and light truck fleet must be determined according to paragraph (b)(2)(ii) of this section to determine whether the applicable limitation has been exceeded.

* * * * *

(v) The manufacturer's combined passenger automobile and light truck fleet average off-cycle credits attributable to use of the default credit values in paragraph (b)(1) of this section may not exceed the following specific values:

Model year	Off-cycle credit cap (g/mile)
(A) 2023–2026	15
(B) 2027–2030	10
(C) 2031	8.0
(D) 2032	6.0

* * * * *

(c) *Technology demonstration using EPA 5-cycle methodology.* To demonstrate an off-cycle technology and to determine off-cycle credits using the EPA 5-cycle methodology, the manufacturer shall determine the off-cycle city/highway combined carbon-related exhaust emissions benefit by using the EPA 5-cycle methodology described in 40 CFR part 600. This method may not be used for technologies that include elements (e.g., driver-selectable systems) that require additional analyses, data collection, projections, or modeling, or other assessments to determine a national average benefit of the technology. Testing shall be performed on a representative vehicle, selected using good engineering judgment, for each model type for which the credit is being demonstrated. The emission benefit of a technology is determined by testing both with and without the off-cycle technology operating. If a specific technology is not expected to change emissions on one of the five test procedures, the manufacturer may submit an engineering analysis to the EPA that demonstrates that the technology has no effect. If EPA concurs with the analysis, then multiple tests are not required using that test procedure; instead, only one of that test procedure shall be required—either with or without the technology installed and operating—and that single value will be used for all of the 5-cycle weighting calculations. Multiple off-cycle technologies may be demonstrated on a test vehicle. The manufacturer shall conduct the following steps and submit all test data to the EPA.

* * * * *

(e) * * *

(2) * * *

(i) A detailed description of the off-cycle technology and how it functions to improve fuel economy under conditions not represented on the FTP and HFET.

* * * * *

§ 86.1870–12 [Removed]

■ 44. Remove § 86.1870–12.

PART 600—FUEL ECONOMY AND GREENHOUSE GAS EXHAUST EMISSIONS OF MOTOR VEHICLES

■ 45. The authority citation for part 600 continues to read as follows:

Authority: 49 U.S.C. 32901–23919q, Pub. L. 109–58.

§ 600.001 [Amended]

■ 46. Amend § 600.001 by removing the last sentence in paragraph (a) and the last two sentences in paragraph (c).

■ 47. Amend § 600.002 by:

■ a. Revising the definitions of “Carbon-related exhaust emissions (CREE)” and “Engine code”;

■ b. Removing the definition of “Footprint”; and

■ c. Revising the definitions of “Medium-duty passenger vehicle (MDPV_{FE})”, “Subconfiguration”, and “Vehicle configuration”.

The revisions read as follows:

§ 600.002 Definitions.

* * * * *

Carbon-related exhaust emissions (CREE) means the summation of the carbon-containing constituents of the exhaust emissions, with each constituent adjusted by a coefficient representing the carbon weight fraction of each constituent relative to the CO₂ carbon weight fraction, as specified in § 600.113.

* * * * *

Engine code means a unique combination, within a test group (as defined in § 86.1803 of this chapter), of displacement, fuel injection (or carburetion or other fuel delivery system), calibration, distributor calibration, choke calibration, auxiliary emission control devices, and other engine and emission control system components specified by the Administrator. For electric vehicles, *engine code* means a unique combination of manufacturer, electric traction motor, motor configuration, motor controller, and energy storage device.

* * * * *

Medium-duty passenger vehicle (MDPV_{FE}) means any motor vehicle rated at more than 8,500 pounds GVWR and less than 10,000 pounds GVWR that is designed primarily to transport passengers, but does not include a vehicle that—

(1) Is an “incomplete truck,” meaning any truck which does not have the primary load carrying device or container attached when it is first sold as a vehicle; or

(2) Has a seating capacity of more than 12 persons; or

(3) Is designed for more than 9 persons in seating rearward of the driver’s seat; or

(4) Is equipped with an open cargo area (for example, a pick-up truck box or bed) of 72.0 inches in interior length or more. A covered box not readily accessible from the passenger compartment will be considered an open cargo area for purposes of this definition. (See paragraph (1) of the definition of medium-duty passenger vehicle at 40 CFR 86.1803–01).

* * * * *

Subconfiguration means a unique combination within a vehicle configuration of equivalent test weight, road-load horsepower, and any other operational characteristics or parameters which the Administrator determines may significantly affect fuel economy or CO₂ emissions within a vehicle configuration.

* * * * *

Vehicle configuration means a unique combination of basic engine, engine code, inertia weight class, transmission configuration, and axle ratio within a base level.

* * * * *

■ 48. Amend § 600.006 by revising paragraphs (c)(5), (e), and (g)(3)(ii) to read as follows:

§ 600.006 Data and information requirements for fuel economy data vehicles.

* * * * *

(c) * * *

(5) Starting with the 2012 model year, the data submitted according to paragraphs (c)(1) through (4) of this section shall include total HC, CO, CO₂, and, where applicable for alternative fuel vehicles, CH₃OH, C₂H₅OH, C₂H₄O, HCHO, NMHC and CH₄.

* * * * *

(e) In lieu of submitting actual data from a test vehicle, a manufacturer may provide fuel economy and CO₂ emission values derived from a previously tested vehicle, where the fuel economy and CO₂ emissions are expected to be equivalent (or less fuel-efficient and with higher CO₂ emissions). Additionally, in lieu of submitting actual data from a test vehicle, a manufacturer may provide fuel economy and CO₂ emission values derived from an analytical expression, e.g., regression analysis. In order for fuel economy and CO₂ emission values derived from analytical methods to be accepted, the expression (form and coefficients) must have been approved by the Administrator.

* * * * *

(g) * * *

(3) * * *

(ii)(A) The manufacturer shall adjust all CO₂ test data generated by vehicles with engine-drive system combinations with more than 6,200 miles by using the following equation:

$$ADJ_{4,000mi} = TEST[0.979 + 5.25 \cdot 10^{-6} \cdot (mi)]$$

Where:

$ADJ_{4,000mi}$ = CO₂ emission data adjusted to 4,000-mile test point.

TEST = Tested emissions value of CO₂ in grams per mile.

mi = System miles accumulated at the start of the test rounded to the nearest whole mile.

(B) Emissions test values and results used and determined in the calculations in this paragraph (g)(3)(ii) shall be rounded in accordance with § 86.1837 of this chapter as applicable. Round results to the nearest gram per mile.

* * * * *

■ 49. Amend § 600.007 by revising paragraphs (b)(5) and (6), (c), and (f) introductory text to read as follows:

§ 600.007 Vehicle acceptability.

* * * * *

(b) * * *

(5) The calibration information submitted under § 600.006(b) must be representative of the vehicle configuration for which the fuel economy and CO₂ emission data were submitted.

(6) Any vehicle tested for fuel economy or CO₂ emissions must be representative of a vehicle which the manufacturer intends to produce under the provisions of a certificate of conformity.

* * * * *

(c) If, based on review of the information submitted under § 600.006(b), the Administrator determines that a fuel economy data vehicle meets the requirements of this section, the fuel economy data vehicle will be judged to be acceptable and fuel economy data from that fuel economy data vehicle will be reviewed pursuant to § 600.008.

* * * * *

(f) All vehicles used to generate fuel economy data, and for which emission standards apply, must be covered by a certificate of conformity under part 86 of this chapter before:

* * * * *

■ 50. Amend § 600.008 by revising the section heading and paragraph (a)(1)(ii) to read as follows:

§ 600.008 Review of fuel economy and CO₂ emission data, testing by the Administrator.

(a) * * *

(1) * * *

(ii) The evaluations, testing, and test data described in this section pertaining to fuel economy shall also be performed for CO₂ emissions, except that CO₂ emissions shall be arithmetically averaged instead of harmonically averaged, and in cases where the manufacturer selects the lowest of several fuel economy results to represent the vehicle, the manufacturer shall select the CO₂ emission value from the test results associated with the lowest selected fuel economy results.

* * * * *

■ 51. Amend § 600.010 by revising paragraphs (c)(1)(ii) and (d) to read as follows:

§ 600.010 Vehicle test requirements and minimum data requirements.

* * * * *

(c) * * *

(1) * * *

(ii)(A) FTP and HFET data from the highest projected model year sales subconfiguration within the highest projected model year sales vehicle configuration for each base level, and

(B) If required under § 600.115, for 2011 and later model year vehicles, US06, SC03 and cold temperature FTP data from the highest projected model year sales subconfiguration within the highest projected model year sales vehicle configuration for each base level. Manufacturers may optionally generate this data for any 2008 through 2010 model years, and, 2011 and later model year vehicles, if not otherwise required.

* * * * *

(d) *Minimum data requirements for the manufacturer's average fuel economy.* For the purpose of calculating the manufacturer's average fuel economy under § 600.510, the manufacturer shall submit FTP (city) and HFET (highway) test data representing at least 90 percent of the manufacturer's actual model year production, by vehicle configuration, for each category identified for calculation under § 600.510–08(a) or § 600.510–12(a)(1).

■ 52. Revise the heading of subpart B as set forth above.

■ 53. Amend § 600.101 by revising paragraph (a)(2) and removing and reserving paragraph (b)(2). The revision reads as follows:

§ 600.101 Testing overview.

* * * * *

(a) * * *

(2) Calculate fuel economy values for vehicle subconfigurations, configurations, base levels, and model types as described in §§ 600.206 and 600.208. Calculate fleet average values

for fuel economy as described in § 600.510. Note that § 600.510(c) describes how to use CREE to determine fuel consumption improvement values for specific cases.

* * * * *

■ 54. Amend § 600.111–08 by revising paragraph (h) to read as follows:

§ 600.111–08 Test procedures.

* * * * *

(h) *Special test procedures.* We may allow or require you to use procedures other than those specified in this section as described in 40 CFR 1066.10(c). For example, special test procedures may be used for advanced technology vehicles, including, but not limited to fuel cell vehicles, hybrid electric vehicles using hydraulic energy storage, and vehicles equipped with hydrogen internal combustion engines. Additionally, we may conduct fuel economy and exhaust emission testing using the special test procedures approved for a specific vehicle.

■ 55. Amend § 600.113–12 by:

■ a. Revising the section heading,

introductory text, and paragraph (g);

■ b. Removing and reserving paragraphs (h)(2), (i)(2), (j)(2), (k)(2), (l)(2), (m)(2);

■ c. Revising paragraph (n);

■ d. Removing and reserving paragraph (o)(2); and

■ e. Revising paragraph (p).

The revisions read as follows:

§ 600.113–12 Fuel economy and CO₂ emission calculations for FTP, HFET, US06, SC03 and cold temperature FTP tests.

The Administrator will use the calculation procedure set forth in this section for all official EPA testing of vehicles fueled with gasoline, diesel, alcohol-based or natural gas fuel. The calculations of the weighted fuel economy values require input of the weighted grams/mile values for total hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO₂); and, additionally for methanol-fueled automobiles, methanol (CH₃OH) and formaldehyde (HCHO); and, additionally for ethanol-fueled automobiles, methanol (CH₃OH), ethanol (C₂H₅OH), acetaldehyde (C₂H₄O), and formaldehyde (HCHO); and additionally for natural gas-fueled vehicles, non-methane hydrocarbons (NMHC) and methane (CH₄). Emissions shall be determined for the FTP, HFET, US06, SC03, and cold temperature FTP tests. Additionally, the specific gravity, carbon weight fraction and net heating value of the test fuel must be determined. The FTP, HFET, US06, SC03, and cold temperature FTP fuel economy values shall be calculated as specified in this section. An example

fuel economy calculation appears in appendix II to this part.

* * * * *

(g) Calculate separate FTP, highway, US06, SC03 and Cold temperature FTP fuel economy values from the grams/mile values for total HC, CO, CO₂ and, where applicable, CH₃OH, C₂H₅OH, C₂H₄O, HCHO, NMHC, N₂O, and CH₄, and the test fuel's specific gravity, carbon weight fraction, net heating value, and additionally for natural gas, the test fuel's composition.

(1) *Emission values for fuel economy calculations.* The emission values (obtained per paragraph (a) through (e) of this section, as applicable) used in the calculations of fuel economy in this section shall be rounded in accordance with § 86.1837 of this chapter. The CO₂ values (obtained per this section, as applicable) used in each calculation of fuel economy in this section shall be rounded to the nearest gram/mile.

(2) [Reserved]

(h)

(1) For gasoline-fueled automobiles tested on a test fuel specified in § 86.113 of this chapter, the fuel economy in miles per gallon is to be calculated using the following equation and rounded to the nearest 0.1 miles per gallon:

$$\text{mpg} = (5174 \times 10^4 \times \text{CWF} \times \text{SG}) / ((\text{CWF} \times \text{HC}) + (0.429 \times \text{CO}) + (0.273 \times \text{CO}_2)) \times ((0.6 \times \text{SG} \times \text{NHV}) + 5471)$$

Where:

HC = Grams/mile HC as obtained in paragraph (g)(1) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(1) of this section.

CO₂ = Grams/mile CO₂ as obtained in paragraph (g)(1) of this section.

CWF = Carbon weight fraction of test fuel as obtained in paragraph (f)(1) of this section and rounded according to paragraph (g)(3) of this section.

NHV = Net heating value by mass of test fuel as obtained in paragraph (f)(1) of this section and rounded according to paragraph (g)(3) of this section.

SG = Specific gravity of test fuel as obtained in paragraph (f)(1) of this section and rounded according to paragraph (g)(3) of this section.

(2) [Reserved]

(i)

(1) For diesel-fueled automobiles, calculate the fuel economy in miles per gallon of diesel fuel by dividing 2778 by the sum of three terms and rounding the quotient to the nearest 0.1 mile per gallon:

(i) (A) 0.866 multiplied by HC (in grams/miles as obtained in paragraph (g)(1) of this section); or

(B) Zero, in the case of cold FTP diesel tests for which HC was not collected, as permitted in § 600.113–08(c);

(ii) 0.429 multiplied by CO (in grams/mile as obtained in paragraph (g)(1) of this section); and

(iii) 0.273 multiplied by CO₂ (in grams/mile as obtained in paragraph (g)(1) of this section).

(2) [Reserved](j)

(1) For methanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and methanol, the

fuel economy in miles per gallon of methanol is to be calculated using the following equation:

$$\text{mpg} = (\text{CWF} \times \text{SG} \times 3781.8) / ((\text{CWF}_{\text{exHC}} \times \text{HC}) + (0.429 \times \text{CO}) + (0.273 \times \text{CO}_2) + (0.375 \times \text{CH}_3\text{OH}) + (0.400 \times \text{HCHO}))$$

Where:

CWF = Carbon weight fraction of the fuel as determined in paragraph (f)(2)(ii) of this section and rounded according to paragraph (g)(3) of this section.

SG = Specific gravity of the fuel as determined in paragraph (f)(2)(i) of this section and rounded according to paragraph (g)(3) of this section.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF as determined in paragraph (f)(2)(ii) of this section and rounded according to paragraph (g)(3) of this section (for M100 fuel, CWF_{exHC} = 0.866).

HC = Grams/mile HC as obtained in paragraph (g)(1) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(1) of this section.

CO₂ = Grams/mile CO₂ as obtained in paragraph (g)(1) of this section.

CH₃OH = Grams/mile CH₃OH (methanol) as obtained in paragraph (g)(1) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g)(1) of this section.

(2) [Reserved]

(k)

(1) For automobiles fueled with natural gas and automobiles designed to operate on gasoline and natural gas, the fuel economy in miles per gallon of natural gas is to be calculated using the following equation:

$$\text{mpg}_{\text{NG}} = \frac{\text{CWF}_{\text{HC/NG}} \times D_{\text{NG}} \times 121.5}{(0.749 \times \text{CH}_4) + (\text{CWF}_{\text{NMHC}} \times \text{NMHC}) + (0.429 \times \text{CO}) + (0.273 \times (\text{CO}_1 - \text{CO}_{2\text{NG}}))}$$

Where:

mpg_{NG} = miles per gasoline gallon equivalent of natural gas.

CWF_{HC/NG} = carbon weight fraction based on the hydrocarbon constituents in the natural gas fuel as obtained in paragraph (f)(3) of this section and rounded according to paragraph (g)(3) of this section.

D_{NG} = density of the natural gas fuel [grams/ft³ at 68 °F (20 °C) and 760 mm Hg (101.3

kPa)] pressure as obtained in paragraph (g)(3) of this section.

CH₄, NMHC, CO, and CO₂ = weighted mass exhaust emissions [grams/mile] for methane, non-methane HC, carbon monoxide, and carbon dioxide as obtained in paragraph (g)(2) of this section.

CWF_{NMHC} = carbon weight fraction of the non-methane HC constituents in the fuel as determined from the speciated fuel

composition per paragraph (f)(3) of this section and rounded according to paragraph (g)(3) of this section.

CO_{2NG} = grams of carbon dioxide in the natural gas fuel consumed per mile of travel.

CO_{2NG} = FC_{NG} × D_{NG} × WF_{CO2}

Where:

$$\text{FC}_{\text{NG}} = \frac{(0.749 \times \text{CH}_4) + (\text{CWF}_{\text{NMHC}} \times \text{NMHC}) + (0.429 \times \text{CO}) + (0.273 \times \text{CO}_2)}{\text{CWF}_{\text{NG}} \times D_{\text{NG}}}$$

= cubic feet of natural gas fuel consumed per mile

Where:

CWF_{NG} = the carbon weight fraction of the natural gas fuel as calculated in paragraph (f)(3) of this section.

WF_{CO2} = weight fraction carbon dioxide of the natural gas fuel calculated using the mole fractions and molecular weights of the natural gas fuel constituents per

ASTM D 1945 (incorporated by reference in § 600.011).

(2) [Reserved]

(l)

(1) For ethanol-fueled automobiles and automobiles designed to operate on mixtures of gasoline and ethanol, the fuel economy in miles per gallon of ethanol is to be calculated using the following equation:

$$\text{mpg} = (\text{CWF} \times \text{SG} \times 3781.8) / ((\text{CWF}_{\text{exHC}} \times \text{HC}) + (0.429 \times \text{CO}) + (0.273 \times \text{CO}_2) + (0.375 \times \text{CH}_3\text{OH}) + (0.400 \times \text{HCHO}) + (0.521 \times \text{C}_2\text{H}_5\text{OH}) + (0.545 \times \text{C}_2\text{H}_4\text{O}))$$

Where:

CWF = Carbon weight fraction of the fuel as determined in paragraph (f)(4) of this

section and rounded according to paragraph (f)(3) of this section.

SG = Specific gravity of the fuel as determined in paragraph (f)(4) of this section and rounded according to paragraph (f)(3) of this section.

CWF_{exHC} = Carbon weight fraction of exhaust hydrocarbons = CWF as determined in paragraph (f)(4) of this section and rounded according to paragraph (f)(3) of this section.

HC = Grams/mile HC as obtained in paragraph (g)(1) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(1) of this section.

CO₂ = Grams/mile CO₂ as obtained in paragraph (g)(1) of this section.

CH₃OH = Grams/mile CH₃OH (methanol) as obtained in paragraph (g)(1) of this section.

HCHO = Grams/mile HCHO (formaldehyde) as obtained in paragraph (g)(1) of this section.

C₂H₅OH = Grams/mile C₂H₅OH (ethanol) as obtained in paragraph (g)(1) of this section.

C₂H₄O = Grams/mile C₂H₄O (acetaldehyde) as obtained in paragraph (g)(1) of this section.

(2) [Reserved]

(m)

(1) For automobiles fueled with liquefied petroleum gas and automobiles designed to operate on gasoline and liquefied petroleum gas, the fuel economy in miles per gallon of liquefied petroleum gas is to be calculated using the following equation:

$$\text{mpg}_e = \frac{\text{CWF}_{\text{fuel}} \cdot \text{SG}_{\text{fuel}} \cdot 3781.8}{\text{CWF}_{\text{HC}} \cdot \text{HC} + 0.429 \cdot \text{CO} + 0.273 \cdot \text{CO}_2}$$

Where:

mpg_e = miles per gasoline gallon equivalent of liquefied petroleum gas.

CWF_{fuel} = carbon weight fraction based on the hydrocarbon constituents in the liquefied petroleum gas fuel as obtained in paragraph (f)(5) of this section and rounded according to paragraph (g)(3) of this section.

SG = Specific gravity of the fuel as determined in paragraph (f)(5) of this section and rounded according to paragraph (g)(3) of this section.

3781.8 = Grams of H₂O per gallon conversion factor.

CWF_{HC} = Carbon weight fraction of exhaust hydrocarbon = CWF_{fuel} as determined in paragraph (f)(4) of this section and rounded according to paragraph (f)(3) of this section.

HC = Grams/mile HC as obtained in paragraph (g)(2) of this section.

CO = Grams/mile CO as obtained in paragraph (g)(2) of this section.

CO₂ = Grams/mile CO₂ as obtained in paragraph (g)(2) of this section.

(2) [Reserved]

(n) Manufacturers may use a value of 0 grams CO₂ per mile to represent the emissions of electric vehicles and the electric operation of plug-in hybrid electric vehicles derived from electricity generated from sources that are not onboard the vehicle.

(o)

(1) For testing with E10, calculate fuel economy using the following equation, rounded to the nearest 0.1 miles per gallon:

$$FE_{\text{interval}} = \frac{(\text{CMF}_{\text{testfuel}} \cdot \text{SG}_{\text{testfuel}}) \cdot (\rho_{\text{H}_2\text{O}} \cdot \text{SG}_{\text{basefuel}} \cdot \text{NHC}_{\text{basefuel}})}{[(\text{CMF}_{\text{testfuel}} \cdot \text{NMOG}) + (0.749 \cdot \text{CH}_4) + (0.429 \cdot \text{CO}) + (0.273 \cdot \text{CO}_2)] \cdot [(\text{R}_a \cdot \text{SG}_{\text{testfuel}} \cdot \text{NHC}_{\text{testfuel}}) + (\text{SG}_{\text{basefuel}} \cdot \text{NHC}_{\text{basefuel}} \cdot (1 - \text{R}_a))]}$$

Where:

CMF_{testfuel} = carbon mass fraction of the test fuel, expressed to three decimal places.

SG_{testfuel} = the specific gravity of the test fuel as obtained in paragraph (f)(1) of this section, expressed to three decimal places.

ρ_{H₂O} = the density of pure water at 60 °F. Use ρ_{H₂O} = 3781.69 g/gal.

SG_{basefuel} = the specific gravity of the 1975 base fuel. Use SG_{basefuel} = 0.7394.

NHC_{basefuel} = net heat of combustion of the 1975 base fuel. Use NHC_{basefuel} = 43.047 MJ/kg.

NMOG = NMOG emission rate over the test interval or duty cycle in grams/mile.

CH₄ = CH₄ emission rate over the test interval or duty cycle in grams/mile.

CO = CO emission rate over the test interval or duty cycle in grams/mile.

CO₂ = measured tailpipe CO₂ emission rate over the test interval or duty cycle in grams/mile.

R_a = sensitivity factor that represents the response of a typical vehicle's fuel

economy to changes in fuel properties, such as volumetric energy content. Use R_a = 0.81.

NHC_{testfuel} = net heat of combustion by mass of test fuel as obtained in paragraph (f)(1) of this section, expressed to three decimal places.

(2) [Reserved]

(p) Equations for fuels other than those specified in this section may be used with advance EPA approval. Alternate calculation methods for fuel economy may be used in lieu of the methods described in this section if shown to yield equivalent or superior results and if approved in advance by the Administrator.

■ 56. Amend § 600.114–12 by revising the section heading and introductory text to read as follows:

§ 600.114–12 Vehicle-specific 5-cycle fuel economy CO₂ emission calculations.

Paragraphs (a) through (f) of this section apply to data used for fuel economy labeling under subpart D of this part. Paragraphs (d) through (f) of this section are used to calculate 5-cycle carbon-related exhaust emission values for the purpose of determining optional credits for CO₂-reducing technologies under § 86.1869–12 of this chapter and to calculate 5-cycle CO₂ values for the purpose of fuel economy labeling under subpart D of this part.

* * * * *

■ 57. Amend § 600.116–12 by revising paragraphs (a)(11)(iii)(E), (c)(1) introductory text, and (c)(6)(iii) to read as follows:

§ 600.116–12 Special procedures related to electric vehicles and hybrid electric vehicles.

- (a) * * *
(11) * * *
(iii) * * *

(E) A description of each test group and vehicle configuration that will use the 5-cycle adjustment factor, including the battery capacity of the vehicle used to generate the 5-cycle adjustment factor and the battery capacity of all the vehicle configurations to which it will be applied.

* * * * *

(c) Determine performance values for hybrid electric vehicles that have plug-in capability as specified in §§ 600.210 and 600.311 using the procedures of SAE J1711 (incorporated by reference in § 600.011), with the following clarifications and modifications:

(1) Calculate fuel economy values representing combined operation during charge-depleting and charge-sustaining operation using the following utility factors, except as otherwise specified in this paragraph (c):

* * * * *

- (6) * * *

(iii) For charge-sustaining tests, we may approve alternate Net Energy Change/Fuel Ratio tolerances as specified in Appendix C of SAE J1711 to correct final fuel economy values and CO₂ emissions. For charge-sustaining tests, do not use alternate Net Energy Change/Fuel Ratio tolerances to correct emissions of criteria pollutants. Additionally, if we approve an alternate End-of-Test criterion or Net Energy Change/Fuel Ratio tolerances for a specific vehicle, we may use the alternate criterion or tolerances for any testing we conduct on that vehicle.

* * * * *

■ 58. Amend § 600.117 by removing and reserving paragraph (a)(5) and revising paragraphs (a)(6) and (b) to read as follows:

§ 600.117 Interim provisions.

- (a) * * *

(6) Manufacturers may alternatively determine fuel economy values using E10 gasoline test fuel as specified in 40 CFR 1065.710(b). Calculate fuel economy using the equation specified in § 600.113–12(o)(1) based on measured CO₂ results without adjusting to account for fuel effects.

* * * * *

(b) For model years 2027 through 2029, manufacturers may determine fuel economy values using data with E0 test fuel from testing for earlier model years, subject to the carryover provisions of 40 CFR 86.1839 and § 600.006. Calculate

fuel economy using the equation specified in § 600.113–12(h)(1) based on measured CO₂ results without adjusting to account for fuel effects.

* * * * *

■ 59. Amend § 600.206–12 by revising paragraphs (a) introductory text, (a)(4) introductory text, (b), and (c) to read as follows:

§ 600.206–12 Calculation and use of FTP-based and HFET-based fuel economy, CO₂ emissions, and carbon-related exhaust emission values for vehicle configurations.

(a) Fuel economy, CO₂ emissions, and carbon-related exhaust emissions values determined for each vehicle under § 600.113–12(a) and (b) and as approved in § 600.008(c), are used to determine FTP-based city, HFET-based highway, and combined FTP/Highway-based fuel economy, CO₂ emissions, and carbon-related exhaust emission values for each vehicle configuration for which data are available. Note that fuel economy for some alternative fuel vehicles may mean miles per gasoline gallon equivalent and/or miles per unit of fuel consumed. For example, electric vehicles will determine miles per kilowatt-hour in addition to miles per gasoline gallon equivalent, and fuel cell vehicles will determine miles per kilogram of hydrogen.

* * * * *

(4) For alcohol dual fuel automobiles and natural gas dual fuel automobiles the procedures of paragraphs (a)(1) or (2) of this section, as applicable, shall be used to calculate two separate sets of FTP-based city, HFET-based highway, and combined values for fuel economy, CO₂ emissions, and carbon-related exhaust emissions for each vehicle configuration.

* * * * *

(b) If only one equivalent petroleum-based fuel economy value exists for an electric vehicle configuration, that value, rounded to the nearest tenth of a mile per gallon, will comprise the petroleum-based fuel economy for that vehicle configuration.

(c) If more than one equivalent petroleum-based fuel economy value exists for an electric vehicle configuration, all values for that vehicle configuration are harmonically averaged and rounded to the nearest 0.0001 mile per gallon for that vehicle configuration.

■ 60. Amend § 600.207–12 by revising paragraphs (a)(1), (a)(4) introductory text, (b), and (c) to read as follows:

§ 600.207–12 Calculation and use of vehicle-specific 5-cycle-based fuel economy and CO₂ emission values for vehicle configurations.

- (a) * * *

(1) If only one set of 5-cycle city and highway fuel economy and CO₂ emission values is accepted for a vehicle configuration, these values, where fuel economy is rounded to the nearest 0.0001 of a mile per gallon and the CO₂ emission value in grams per mile is rounded to the nearest tenth of a gram per mile, comprise the city and highway fuel economy and CO₂ emission values for that vehicle configuration. Note that the appropriate vehicle-specific CO₂ values for fuel economy labels based on 5-cycle testing with E10 test fuel are adjusted as described in § 600.114–12.

* * * * *

(4) For alcohol dual fuel automobiles and natural gas dual fuel automobiles, the procedures of paragraphs (a)(1) and (2) of this section shall be used to calculate two separate sets of 5-cycle city and highway fuel economy and CO₂ emission values for each vehicle configuration.

* * * * *

(b) If only one equivalent petroleum-based fuel economy value exists for an electric vehicle configuration, that value, rounded to the nearest tenth of a mile per gallon, will comprise the petroleum-based 5-cycle fuel economy for that vehicle configuration.

(c) If more than one equivalent petroleum-based 5-cycle fuel economy value exists for an electric vehicle configuration, all values for that vehicle configuration are harmonically averaged and rounded to the nearest 0.0001 mile per gallon for that vehicle configuration.

■ 61. Amend § 600.210–12 by revising paragraph (b) to read as follows:

§ 600.210–12 Calculation of fuel economy and CO₂ emission values for labeling.

* * * * *

(b) *Specific labels.* Except as specified in paragraphs (d) and (e) of this section, fuel economy and CO₂ emissions for specific labels may be determined by one of two methods. The first is based on vehicle-specific vehicle configuration 5-cycle data as determined in § 600.207. This method is available for all vehicles and is required for vehicles that do not qualify for the second method as described in § 600.115 (other than electric vehicles). The second method, the derived 5-cycle method, determines fuel economy and CO₂ emissions values from the FTP and HFET tests using equations that are derived from vehicle-specific 5-cycle vehicle configuration data, as determined in paragraph (b)(2) of this section. Manufacturers may voluntarily lower fuel economy values and raise CO₂ values if they determine that the label values from either method are not

representative of the fuel economy or CO₂ emissions for that model type.

(1) *Vehicle-specific 5-cycle labels.* The city and highway vehicle configuration fuel economy determined in § 600.207, rounded to the nearest mpg, and the city and highway vehicle configuration CO₂

emissions determined in § 600.207, rounded to the nearest gram per mile, comprise the fuel economy and CO₂ emission values for specific fuel economy labels, or, alternatively;

(2) *Derived 5-cycle labels.* Specific city and highway label values from

derived 5-cycle are determined according to the following method:

(i)(A) Determine the derived five-cycle city fuel economy of the vehicle configuration using the equation below and coefficients determined by the Administrator:

Derived 5 – cycle City Fuel Economy

$$= \frac{1}{(\text{City Intercept}) + \frac{(\text{City Slope})}{\text{Config FTP FE}}}$$

Where:

City Intercept = Intercept determined by the Administrator based on historic vehicle-specific 5-cycle city fuel economy data.

City Slope = Slope determined by the Administrator based on historic vehicle-specific 5-cycle city fuel economy data.

Config FTP FE = the vehicle configuration FTP-based city fuel economy determined under § 600.206, rounded to the nearest 0.0001 mpg.

(B) Determine the derived five-cycle city CO₂ emissions of the vehicle

configuration using the equation below and coefficients determined by the Administrator:

Derived 5-cycle City CO₂ = City Intercept + City Slope · Config FTP CO₂

Where:

City Intercept = Intercept determined by the Administrator based on historic vehicle-specific 5-cycle city fuel economy data.

City Slope = Slope determined by the Administrator based on historic vehicle-specific 5-cycle city fuel economy data.

Config FTP CO₂ = the vehicle configuration FTP-based city CO₂ emissions determined under § 600.206, rounded to the nearest 0.1 grams per mile. Note that the appropriate Config FTP CO₂ input values for fuel economy labels based on testing with E10 test fuel are adjusted as referenced in § 600.206–12(a)(2)(iii).

(ii)(A) Determine the derived five-cycle highway fuel economy of the vehicle configuration using the equation below and coefficients determined by the Administrator:

Derived 5 – cycle Highway Fuel Economy

$$= \frac{1}{(\text{Highway Intercept}) + \frac{(\text{Highway Slope})}{\text{Config HFET FE}}}$$

Where:

Highway Intercept = Intercept determined by the Administrator based on historic vehicle-specific 5-cycle highway fuel economy data.

Highway Slope = Slope determined by the Administrator based on historic vehicle-specific 5-cycle highway fuel economy data.

Config HFET FE = the vehicle configuration highway fuel economy determined under § 600.206, rounded to the nearest tenth.

(B) Determine the derived five-cycle highway CO₂ emissions of the vehicle configuration using the equation below and coefficients determined by the Administrator:

Derived 5-cycle city Highway CO₂ = Highway Intercept + Highway Slope · Config HFET CO₂

Where:

Highway Intercept = Intercept determined by the Administrator based on historic vehicle-specific 5-cycle highway fuel economy data.

Highway Slope = Slope determined by the Administrator based on historic vehicle-specific 5-cycle highway fuel economy data.

Config HFET CO₂ = the vehicle configuration highway fuel economy determined under § 600.206, rounded to the nearest tenth. Note that the appropriate Config HFET CO₂ input values for fuel economy labels based on testing with E10 test fuel are

adjusted as referenced in § 600.206–12(a)(2)(iii).

(iii) The slopes and intercepts of paragraph (a)(2)(iii) of this section apply.

(3) *Specific alternative fuel economy and CO₂ emissions label values for dual fuel vehicles.*

(i) Determine an alternative fuel label value for dual fuel vehicles, rounded to the nearest whole number, as follows:

(A) Specific city and highway fuel economy label values for dual fuel alcohol-based and natural gas vehicles when using the alternative fuel are separately determined by the following calculation:

$$\text{Derived } FE_{alt} = FE_{alt} \times \frac{5 \text{ cycle}_{gas}}{FE_{gas}}$$

Where:

FE_{alt} = The unrounded FTP-based vehicle configuration city or HFET-based vehicle configuration highway fuel economy

from the alternative fuel, as determined in § 600.206.

5cycle FE_{gas} = The unrounded vehicle-specific or derived 5-cycle vehicle configuration city or highway fuel

economy as determined in paragraph (b)(1) or (2) of this section.

FE_{gas} = The unrounded FTP-based city or HFET-based vehicle configuration

highway fuel economy from gasoline, as determined in § 600.206.

(B) Specific city and highway CO₂ emission label values for dual fuel alcohol-based and natural gas vehicles

when using the alternative fuel are separately determined by the following calculation:

$$\text{Derived } CO_{2alt} = CO_{2alt} \times \frac{5 \text{ cycle } CO_{2gas}}{CO_{2gas}}$$

Where:

CO_{2alt} = The unrounded FTP-based vehicle configuration city or HFET-based vehicle configuration highway CO₂ emissions value from the alternative fuel, as determined in § 600.206.

5cycle CO_{2gas} = The unrounded vehicle-specific or derived 5-cycle vehicle configuration city or highway CO₂ emissions value as determined in paragraph (b)(1) or (b)(2) of this section.

CO_{2gas} = The unrounded FTP-based city or HFET-based vehicle configuration highway CO₂ emissions value from gasoline, as determined in § 600.206.

(ii) Optionally, if complete 5-cycle testing has been performed using the alternative fuel, the manufacturer may choose to use the alternative fuel label city or highway fuel economy and CO₂ emission values determined in § 600.207–12(a)(4)(ii), rounded to the nearest whole number.

(4) *Specific alternative fuel economy and CO₂ emissions label values for electric vehicles.* Determine FTP-based city and HFET-based highway fuel economy label values for electric vehicles as described in § 600.116. Determine these values by running the appropriate repeat test cycles. Convert W-hour/mile results to miles per kW-hr and miles per gasoline gallon equivalent. CO₂ label information is based on tailpipe emissions only, so CO₂ emissions from electric vehicles are assumed to be zero.

(5) *Specific alternate fuel economy and CO₂ emissions label values for fuel cell vehicles.* Determine FTP-based city and HFET-based highway fuel economy label values for fuel cell vehicles using procedures specified by the Administrator. Convert kilograms of hydrogen/mile results to miles per kilogram of hydrogen and miles per gasoline gallon equivalent. CO₂ label information is based on tailpipe emissions only, so CO₂ emissions from fuel cell vehicles are assumed to be zero.

* * * * *

■ 62. Revise the heading of subpart F as set forth above.

■ 63. Amend § 600.507–12 by revising paragraphs (a) introductory text, (b), and (d) to read as follows:

§ 600.507–12 Running change data requirements.

(a) Except as specified in paragraph (d) of this section, the manufacturer shall submit additional running change fuel economy data as specified in paragraph (b) of this section for any running change approved or implemented under § 86.1842 of this chapter, which:

* * * * *

(b)(1) The additional running change fuel economy data requirement in paragraph (a) of this section will be determined based on the sales of the vehicle configurations in the created or affected base level(s) as updated at the time of running change approval.

(2) Within each newly created base level as specified in paragraph (a)(1) of this section, the manufacturer shall submit data from the highest projected total model year sales subconfiguration within the highest projected total model year sales vehicle configuration in the base level.

(3) Within each base level affected by a running change as specified in paragraph (a)(2) of this section, fuel economy data shall be submitted for the vehicle configuration created or affected by the running change which has the highest total model year projected sales. The test vehicle shall be of the subconfiguration created by the running change which has the highest projected total model year sales within the applicable vehicle configuration.

* * * * *

(d) For those model types created under § 600.208–12(a)(2), the manufacturer shall submit fuel economy data for each subconfiguration added by a running change.

■ 64. Revise § 600.509–12 to read as follows:

§ 600.509–12 Voluntary submission of additional data.

(a) The manufacturer may optionally submit data in addition to the data required by the Administrator.

(b) Additional fuel economy data may be submitted by the manufacturer for any vehicle configuration which is to be tested as required in § 600.507 or for which fuel economy data were previously submitted under paragraph (c) of this section.

(c) Within a base level, additional fuel economy data may be submitted by the manufacturer for any vehicle configuration which is not required to be tested by § 600.507.

■ 65. Amend § 600.510–12 by:

■ a. Revising the section heading;

■ b. Removing and reserving paragraph (a)(2);

■ c. Revising paragraphs (b) and (g)(1) introductory text; and

■ d. Removing paragraphs (i), (j), and (k).

The revisions read as follows:

§ 600.510–12 Calculation of average fuel economy.

* * * * *

(b) For the purpose of calculating average fuel economy under paragraph (c) of this section:

(1) All fuel economy data submitted in accordance with § 600.006(e) or § 600.512(c) shall be used.

(2) The combined city/highway fuel economy values will be calculated for each model type in accordance with § 600.208 except that:

(i) Separate fuel economy values will be calculated for model types and base levels associated with car lines for each category of passenger automobiles and light trucks as determined by the Secretary of Transportation pursuant to paragraph (a)(1) of this section.

(ii) Total model year production data, as required by this subpart, will be used instead of sales projections;

(iii) [Reserved]

(iv) The fuel economy value will be rounded to the nearest 0.1 mpg; and

(v) [Reserved]

(vi) At the manufacturer's option, those vehicle configurations that are self-compensating to altitude changes may be separated by sales into high-altitude sales categories and low-altitude sales categories. These separate sales categories may then be treated (only for the purpose of this section) as separate vehicle configurations in accordance with the procedure of § 600.208–12(a)(4)(ii).

(3) The fuel economy values for each vehicle configuration are the combined fuel economy calculated according to § 600.206–12(a)(3) except that:

(i) Separate fuel economy values will be calculated for vehicle configurations

associated with car lines for each category of passenger automobiles and light trucks as determined by the Secretary of Transportation pursuant to paragraph (a)(1) of this section; and

(ii) Total model year production data, as required by this subpart will be used instead of sales projections.

* * * * *

(g)(1) Dual fuel automobiles must provide equal or greater energy efficiency while operating on the alternative fuel as while operating on gasoline or diesel fuel to obtain the CAFE credit determined in paragraphs (c)(2)(iv) and (v) of this section. The following equation must hold true:

* * * * *

■ 66. Amend § 600.512–12 by:

■ a. Revising paragraph (a) introductory text;

■ b. Removing and reserving paragraph (a)(2), (c)(1)(ii), and (c)(2)(ii);

■ c. Revising paragraphs (c)(3);

■ d. Removing and reserving paragraphs (c)(4)(ii), and (c)(5)(ii); and

■ e. Removing paragraph (c)(11).

The revisions read as follows:

§ 600.512–12 Model year report.

(a) For each model year, the manufacturer shall submit to the Administrator a report, known as the model year report, containing all information necessary for the calculation of the manufacturer's average fuel economy.

(c) * * *

(3)(i) For manufacturers calculating air conditioning efficiency credits in support of fuel consumption improvement values under § 600.510(c), a description of the air conditioning system and the total credits earned for each averaging set, model year, and region, as applicable.

(ii) Any additional fuel economy data submitted by the manufacturer under § 600.509;

* * * * *

§ 600.514–12 [Removed]

■ 67. Remove § 600.514–12.

PART 1036—CONTROL OF EMISSIONS FROM NEW AND IN-USE HEAVY-DUTY HIGHWAY ENGINES

■ 68. The authority citation for part 1036 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

■ 69. Amend § 1036.1 by revising paragraph (a) introductory text to read as follows:

§ 1036.1 Applicability.

(a) Except as specified in § 1036.5, the provisions of this part apply for engines that will be installed in heavy-duty

vehicles (including glider vehicles). Heavy-duty engines produced before December 20, 2026 are subject to exhaust emission standards for NO_x, HC, PM, and CO, and related provisions under 40 CFR part 86, subpart A and subpart N, instead of this part, except as follows:

* * * * *

■ 70. Amend § 1036.5 by revising paragraph (a) and removing paragraph (e). The revision reads as follows:

§ 1036.5 Excluded engines.

(a) The provisions of this part do not apply to engines used in medium-duty passenger vehicles or other heavy-duty vehicles that are subject to regulation under 40 CFR part 86, subpart S, except as specified in 40 CFR part 86, subpart S. For example, this exclusion may apply for engines used in incomplete vehicles or high-GCWR vehicles as specified in 40 CFR 86.1801–12.

* * * * *

■ 71. Amend § 1036.15 by revising paragraph (b) to read as follows:

§ 1036.15 Other applicable regulations.

* * * * *

(b) Part 1037 of this chapter describes emission standards and other requirements for heavy-duty vehicles, whether or not they use engines certified under this part.

* * * * *

■ 72. Amend § 1036.101 by revising paragraph (a) to read as follows:

§ 1036.101 Overview of exhaust emission standards.

(a) You must show that engines meet the criteria pollutant standards for NO_x, HC, PM, and CO as described in § 1036.104. These pollutants are sometimes described collectively as “criteria pollutants” because they are either criteria pollutants under the Clean Air Act or precursors to the criteria pollutants ozone and PM.

* * * * *

§ 1036.108 [Removed]

■ 73. Remove § 1036.108.

§ 1036.115 [Amended]

■ 74. Amend § 1036.115 by removing and reserving paragraph (b).

■ 75. Amend § 1036.130 by revising paragraph (b)(5) and removing and reserving paragraph (c). The revision reads as follows:

§ 1036.130 Installation instructions for vehicle manufacturers.

* * * * *

(b) * * *

(5) Describe how your certification is limited for any type of application. For

example, if you certify engines only for use in emergency vehicles, you must make clear that the engine may only be installed in emergency vehicles.

* * * * *

■ 76. Amend § 1036.135 by revising paragraphs (c)(9) and (e) to read as follows:

§ 1036.135 Labeling.

* * * * *

(c) * * *

(9) Identify any limitations on your certification. For example, if you certify engines with one or more approved AECDs for emergency vehicle applications under § 1036.115(h)(4), include the statement: “THIS ENGINE IS FOR INSTALLATION IN EMERGENCY VEHICLES ONLY”.

* * * * *

(e) You may ask us to approve modified labeling requirements in this part if you show that it is necessary or appropriate. We will approve your request if your alternate label is consistent with the requirements of this part.

* * * * *

■ 77. Amend § 1036.150 by:

■ a. Removing and reserving paragraphs (b), (d), and (e);

■ b. Revising paragraph (f);

■ c. Removing and reserving paragraphs (g) through (j), (l) through (n), (p) through (s), and (w); and

■ d. Removing paragraph (aa).

The revision reads as follows:

§ 1036.150 Interim provisions.

* * * * *

(f) *Testing exemption for hydrogen engines.* Tailpipe HC, and CO emissions from engines fueled with neat hydrogen are deemed to comply with the applicable standard. Testing for HC or CO is optional under this part for these engines.

* * * * *

■ 78. Amend § 1036.205 by revising paragraphs (b) introductory text, (l), (m), (o)(2), and (t) and removing paragraph (aa). The revisions read as follows:

§ 1036.205 Requirements for an application for certification.

* * * * *

(b) Explain how the emission control system operates. Describe in detail all system components for controlling criteria pollutant emissions, including all auxiliary emission control devices (AECDs) and all fuel-system components you will install on any production or test engine. Identify the part number of each component you describe. For this paragraph (b), treat as separate AECDs any devices that

modulate or activate differently from each other. Include all the following:

* * * * *

(l) Identify the duty-cycle emission standards from § 1036.104(a) and (b) that apply for the engine family. Also identify the NO_x FEL over the FTP for the engine family.

(m) Identify the engine family's deterioration factors and describe how you developed them (see § 1036.240). Present any test data you used for this. For engines designed to discharge crankcase emissions to the ambient atmosphere, use the deterioration factors for crankcase emission to determine deteriorated crankcase emission levels of NO_x, HC, PM, and CO as specified in § 1036.240(e).

* * * * *

(o) * * *

(2) Identify the value of e_{CO2FTP} from § 1036.235(b).

* * * * *

(t) State whether your certification is limited for certain engines. For example, you might certify engines only for use in emergency vehicles or in vehicles with hybrid powertrains. If this is the case, describe how you will prevent use of these engines in vehicles for which they are not certified.

* * * * *

■ 79. Amend § 1036.225 by removing paragraph (a)(3) and revising paragraph (f). The revision reads as follows:

§ 1036.225 Amending applications for certification.

* * * * *

(f) You may ask us to approve a change to your FEL in certain cases after the start of production, but before the end of the model year. The changed FEL may not apply to engines you have already introduced into U.S. commerce, except as described in this paragraph (f). You may ask us to approve a change to your FEL in the following cases:

(1) You may ask to raise your FEL for your engine family at any time. In your request, you must show that you will still be able to meet the emission standards as specified in subparts B and H of this part. Use the appropriate FELs with corresponding production volumes to calculate emission credits for the model year, as described in subpart H of this part.

(2) You may ask to lower the FEL for your engine family only if you have test data from production engines showing that emissions are below the proposed lower FEL. The lower FEL applies only to engines you produce after we approve the new FEL. Use the appropriate FEL with corresponding production volumes to calculate emission credits for the

model year, as described in subpart H of this part.

* * * * *

§ 1036.230 [Amended]

■ 80. Amend § 1036.230 by removing paragraph (f).

■ 81. Add § 1036.231 to subpart C to read as follows:

§ 1036.231 Powertrain families.

(a) If you choose to perform powertrain testing as specified in § 1036.545, use good engineering judgment to divide your product line into powertrain families that are expected to have similar criteria emissions throughout the useful life as described in this section. Your powertrain family is limited to a single model year.

(b) Except as specified in paragraph (c) of this section, group powertrains in the same powertrain family if they share all the following attributes:

(1) Have the same engine design aspects as specified in § 1036.230.

(2) [Reserved]

(3) Number of clutches.

(4) Type of clutch (e.g., wet or dry).

(5) Presence and location of a fluid coupling such as a torque converter.

(6) Gear configuration, as follows:

(i) Planetary (e.g., simple, compound, meshed-planet, stepped-planet, multi-stage).

(ii) Countershaft (e.g., single, double, triple).

(iii) Continuously variable (e.g., pulley, magnetic, toroidal).

(7) Number of available forward gears, and transmission gear ratio for each available forward gear, if applicable. Count forward gears as being available only if the vehicle has the hardware and software to allow operation in those gears.

(8) Transmission oil sump configuration (e.g., conventional or dry).

(9) The power transfer configuration of any hybrid technology (e.g., series or parallel).

(10) The type of any RESS (e.g., hydraulic accumulator, Lithium-ion battery pack, ultracapacitor bank).

(c) For powertrains that share all the attributes described in paragraph (b) of this section, divide them further into separate powertrain families based on common calibration attributes. Group powertrains in the same powertrain family to the extent that powertrain test results and corresponding emission levels are expected to be similar throughout the useful life.

(d) You may subdivide a group of powertrains with shared attributes under paragraph (b) of this section into different powertrain families.

(e) In unusual circumstances, you may group powertrains into the same powertrain family even if they do not have shared attributes under in paragraph (b) of this section if you show that their emission characteristics throughout the useful life will be similar.

(f) If you include the axle when performing powertrain testing for the family, you must limit the family to include only those axles represented by the test results. You may include multiple axle ratios in the family if you test with the axle expected to produce the highest emission results.

■ 82. Amend § 1036.235 by revising the introductory text and paragraphs (a) and (b) and removing and reserving paragraph (c)(5). The revisions read as follows:

§ 1036.235 Testing requirements for certification.

This section describes the emission testing you must perform to show compliance with the emission standards in § 1036.104.

(a) Select and configure one or two emission-data engines from each engine family.

(1) For criteria pollutant emission testing, select the engine configuration with the highest volume of fuel injected per cylinder per combustion cycle at the point of maximum torque—unless good engineering judgment indicates that a different engine configuration is more likely to exceed (or have emissions nearer to) an applicable emission standard or FEL. If two or more engines have the same fueling rate at maximum torque, select the one with the highest fueling rate at rated speed. In making this selection, consider all factors expected to affect emission-control performance and compliance with the standards, including emission levels of all exhaust constituents, especially NO_x and PM. To the extent we allow it for establishing deterioration factors, select for testing those engine components or subsystems whose deterioration best represents the deterioration of in-use engines.

(2) In the case of powertrain testing under § 1036.545, select a test engine, test hybrid components, test axle and test transmission as applicable, by considering the whole range of vehicle models covered by the powertrain family. If the powertrain has more than one transmission calibration, for example economy vs. performance, you may weight the results from the powertrain testing in § 1036.545 by the percentage of vehicles in the family by prior model year for each configuration. This can be done, for example, through

the use of survey data or based on the previous model year's sales volume. Weight the results of $M_{fuel[cycle]}$, $f_{powertrain}/V_{powertrain}$, and $W_{[cycle]}$ from table 5 to paragraph (o)(8)(i) of § 1036.545 according to the percentage of vehicles in the family that use each transmission calibration.

(b) Test your emission-data engines using the procedures and equipment specified in subpart F of this part. In the case of dual-fuel and flexible-fuel engines, measure emissions when operating with each type of fuel for which you intend to certify the engine. For criteria pollutant emission testing, measure NO_x, PM, CO, and NMHC emissions using each duty cycle specified in § 1036.104. Determine brake-specific CO₂ emissions over the FTP, e_{CO_2FTP} , as a reference value for calculating emission rates from in-use engines under § 1036.530, as applicable. You may alternatively determine e_{CO_2FTP} , based on brake-specific CO₂ emissions over the SET, with our advance approval, if you demonstrate that engines from the engine family will be used only with tractors.

* * * * *

§ 1036.241 [Removed]

■ 83. Remove § 1036.241.

■ 84. Amend § 1036.245 by revising paragraph (c)(3) to read as follows:

§ 1036.245 Deterioration factors for exhaust emission standards.

* * * * *

(c) * * *

(3) Perform service accumulation in the laboratory by operating the engine or hybrid powertrain repeatedly over one of the following test sequence, or a different test sequence that we approve in advance:

- (i) Operate at idle for 2 hours.
- (ii) Operate for 105 ± 1 hours over a repeat sequence of one FTP followed by one RMC.
- (iii) Operate over one LLC.
- (iv) Operate at idle for 2 hours.
- (v) Shut down the engine for cooldown to ambient temperature.

* * * * *

■ 85. Revise § 1036.301 to read as follows:

§ 1036.301 Selective enforcement audits.

Selective enforcement audits apply for engines and powertrains as specified in 40 CFR part 1068, subpart E.

■ 86. Amend § 1036.415 by revising paragraph (g) to read as follows:

§ 1036.415 Preparing and testing engines.

* * * * *

(g) For stop-start and automatic engine shutdown systems, override idle-

reduction features if they are adjustable. If those systems are not adjustable, set the 1-Hz emission rate to zero for all regulated pollutants when the idle-reduction feature is active. Do not exclude these data points under § 1036.530(c)(3)(ii). Note that systems are considered “adjustable” if vehicle owners, dealers, or other service outlets can override the idle-reduction features.

■ 87. Amend § 1036.501 by revising paragraphs (a), (d), and (h) to read as follows:

§ 1036.501 General testing provisions.

(a) Use the equipment and procedures specified in this subpart and 40 CFR part 1065 to determine whether engines meet the emission standards in § 1036.104.

* * * * *

(d) If your engine is intended for installation in a vehicle equipped with nonadjustable stop-start technology as described in § 1036.415(g), you may shut the engine down during idle portions of the duty cycle to represent in-use operation. We recommend installing a production engine starter motor and letting the engine's ECM manipulate the starter motor to control the engine stop and start events. Use good engineering judgment to address the effects of dynamometer inertia on restarting the engine by, for example, using a larger starter motor or declutching the engine from the dynamometer during restart.

* * * * *

(h) For testing engines that use regenerative braking through the crankshaft only to power an electric heater for aftertreatment devices, you may use the nonhybrid engine testing procedures in §§ 1036.510, 1036.512, and 1036.514 only if the recovered energy is less than 10 percent of the total positive work for each applicable test interval. Otherwise, use powertrain testing procedures specified for hybrid powertrains to measure emissions. For engines that power an electric heater with a battery, you must meet the requirements related to charge-sustaining operation as described in 40 CFR 1066.501(a)(3).

§ 1036.505 [Removed]

■ 88. Remove § 1036.505.

■ 89. Amend § 1036.510 by:

- a. Revising paragraphs (b)(2) introductory text and (b)(2)(vii) and (viii); and
- b. Removing and reserving paragraph (e).

The revisions read as follows:

§ 1036.510 Supplemental Emission Test.

* * * * *

(b) * * *

(2) Test hybrid powertrains as described in § 1036.545, except as specified in this paragraph (b)(2). Do not compensate the duty cycle for the distance driven as described in § 1036.545(g)(4). For hybrid engines, select the transmission model parameters as described in § 1036.510(b)(viii). Disregard duty cycles in § 1036.545(j). For cycles that begin with idle, leave the transmission in neutral or park for the full initial idle segment. Place the transmission into drive no earlier than 5 seconds before the first nonzero vehicle speed setpoint. For SET testing only, place the transmission into park or neutral when the cycle reaches the final idle segment. Use the following vehicle parameters instead of those in § 1036.545 to define the vehicle model in § 1036.545(a)(3):

* * * * *

(vii) Select a combination of drive axle ratio, k_a , and a tire radius, r , that represents the worst-case combination of top gear ratio, drive axle ratio, and tire size for emissions expected for vehicles in which the hybrid engine or hybrid powertrain will be installed. This is typically the highest axle ratio and smallest tire radius. Disregard configurations or settings corresponding to a maximum vehicle speed below 60 mi/hr in selecting a drive axle ratio and tire radius, unless you can demonstrate that in-use vehicles will not exceed that speed. You may request preliminary approval for selected drive axle ratio and tire radius consistent with the provisions of § 1036.210. If the hybrid engine or hybrid powertrain is used exclusively in vehicles not capable of reaching 60 mi/hr, you may request that we approve an alternate test cycle and cycle-validation criteria as described in 40 CFR 1066.425(b)(5). Note that hybrid engines rely on a specified transmission that is different for each duty cycle; the transmission's top gear ratio therefore depends on the duty cycle, which will in turn change the selection of the drive axle ratio and tire size. For example, § 1036.520 prescribes a different top gear ratio than this paragraph (b)(2).

(viii) If you are certifying a hybrid engine, use a default transmission efficiency of 0.95 and create the vehicle model along with its default transmission shift strategy as described in § 1036.545(a)(3)(ii). Specify the transmission type as Automatic Transmission for all engines and for all duty cycles, except that the transmission type is Automated Manual Transmission for Heavy HDE operating over the SET duty cycle. For automatic transmissions set neutral idle to “Y” in

the vehicle file. Select gear ratios for each gear as shown in the following table:

TABLE 1 TO PARAGRAPH (b)(2)(vii) OF § 1036.510—GEM HIL INPUT FOR GEAR RATIO

Gear number	Spark-ignition HDE, light HDE, and medium HDE— all duty cycles	Heavy HDE— LLC and FTP duty cycles	Heavy HDE— SET duty cycle
1	3.10	3.51	12.8
2	1.81	1.91	9.25
3	1.41	1.43	6.76
4	1.00	1.00	4.90
5	0.71	0.74	3.58
6	0.61	0.64	2.61
7 .....	.....	.....	1.89
8 .....	.....	.....	1.38
9 .....	.....	.....	1.00
10 .....	.....	.....	0.73
Lockup Gear	3	3	.....

* * * * *

■ 90. Amend § 1036.512 by revising paragraphs (b)(2)(iv) and removing and reserving paragraph (e). The revision reads as follows:

§ 1036.512 Federal Test Procedure.

* * * * *

(b) * * *

(2) * * *

(iv) For plug-in hybrid powertrains, test over the FTP in both charge-sustaining and charge-depleting operation for criteria pollutant determination.

* * * * *

■ 91. Amend § 1036.514 by revising paragraph (b)(4) to read as follows:

§ 1036.514 Low Load Cycle.

* * * * *

(b) * * *
(4) Adjust procedures in this section as described in § 1036.510(d) and (e) for plug-in hybrid powertrains to determine criteria pollutant emissions, replacing “SET” with “LLC”. Note that the LLC is therefore the preconditioning duty cycle for plug-in hybrid powertrains.

* * * * *

■ 92. Amend § 1036.520 by revising paragraph (b)(1) to read as follows:

§ 1036.520 Determining power and vehicle speed values for powertrain testing.

* * * * *

(b) * * *

(1) Use vehicle parameters, other than power, as specified in § 1036.510(b)(2).

Use the applicable automatic transmission as specified in § 1036.510(b)(2)(vii).

* * * * *

■ 93. Amend § 1036.530 by revising paragraphs (e) and (g) to read as follows:

§ 1036.530 Test procedures for off-cycle testing.

* * * * *

(e) *Normalized CO₂ emission mass over a 300 second test interval.* For engines subject to compression-ignition standards, determine the normalized CO₂ emission mass over each 300 second test interval, $m_{CO_2, norm, testinterval}$, to the nearest 0.01% using the following equation:

$$m_{CO_2, norm, testinterval} = \frac{m_{CO_2, testinterval}}{e_{CO_2 FTP} \cdot P_{max} \cdot t_{testinterval}}$$

Eq. 1036.530–2

Where:

$m_{CO_2, testinterval}$ = total CO₂ emission mass over the test interval.

$e_{CO_2 FTP}$ = the engine's brake-specific CO₂ over the FTP duty cycle, as described in § 1036.235(b).

P_{max} = the highest value of rated power for all the configurations included in the engine family.

$t_{testinterval}$ = duration of the test interval. Note that the nominal value is 300 seconds.

Example

$m_{CO_2, testinterval}$ = 3948 g

$e_{CO_2 FTP}$ = 428.2 g/hp-hr

P_{max} = 406.5 hp

$t_{testinterval}$ = 300.01 s = 0.08 hr

$$m_{CO_2, norm, testinterval} = \frac{3948}{428.2 \cdot 406.5 \cdot 0.08}$$

$m_{CO_2, norm, testinterval} = 0.2722 = 27.22\%$

* * * * *

(g) *Off-cycle emissions quantities.* Determine the off-cycle emissions quantities as follows:

(1) *Spark-ignition.* For engines subject to spark-ignition standards, the off-cycle emission quantity, $e_{[emission], offcycle}$, is the value for CO₂-specific emission mass for a given pollutant over the test interval

representing the shift-day converted to a brake-specific value, as calculated for each measured pollutant using the following equation:

$$e_{[emissions],offcycle} = \frac{m_{[emission]}}{m_{CO_2}} \cdot e_{CO_2,FTP}$$

Eq. 1036.530–3

Where:

$m_{[emission]}$ = total emission mass for a given pollutant over the test interval as determined in paragraph (d)(2) of this section.

m_{CO_2} = total CO₂ emission mass over the test interval as determined in paragraph (d)(2) of this section.

$e_{CO_2,FTP}$ = the engine's brake-specific CO₂ over the FTP duty cycle.

Example

$m_{NO_x} = 1.337$ g
 $m_{CO_2} = 18778$ g
 $e_{CO_2,FTP} = 505.1$ g/hp-hr

$$e_{NO_x,offcycle} = \frac{1.337}{18778} \cdot 505.1$$

$e_{NO_x, offcycle} = 0.035$ g/hp-hr = 35 mg/hp-hr

(2) *Compression-ignition.* For engines subject to compression-ignition standards, determine the off-cycle emission quantity for each bin. When

calculating mean bin emissions from ten engines to apply the pass criteria for engine families in § 1036.425(c), set any negative off-cycle emissions quantity to zero before calculating mean bin emissions.

(i) *Off-cycle emissions quantity for bin 1.* The off-cycle emission quantity for bin 1, is the mean NO_x mass emission rate from all test intervals associated with bin 1 as calculated using the following equation:

$$\bar{m}_{NO_x,offcycle,bin1} = \frac{\sum_{i=1}^N m_{NO_x,testinterval,i}}{\sum_{i=1}^N t_{testinterval,i}}$$

Eq. 1036.530–4

Where:

i = an indexing variable that represents one 300 second test interval.

N = total number of 300 second test intervals in bin 1.

$m_{NO_x,testinterval,i}$ = total NO_x emission mass over the test interval i in bin 1 as

determined in paragraph (d)(2) of this section.

$t_{testinterval,i}$ = total time of test interval i in bin 1 as determined in paragraph (d)(1) of this section. Note that the nominal value is 300 seconds.

Example

$N = 10114$

$m_{NO_x,testinterval,1} = 0.021$ g

$m_{NO_x,testinterval,2} = 0.025$ g

$m_{NO_x,testinterval,3} = 0.031$ g

$t_{testinterval,1} = 299.99$ s

$t_{testinterval,2} = 299.98$ s

$t_{testinterval,3} = 300.04$ s

$$\bar{m}_{NO_x,offcycle,bin1} = \frac{(0.021 + 0.025 + 0.031 \dots + m_{NO_x,testinterval,10114})}{(299.99 + 299.98 + 300.04 \dots + t_{testinterval,10114})}$$

$\bar{m} = 0.000285$ g/s = 1.026 g/hr

(ii) *Off-cycle emissions quantity for bin 2.* The off-cycle emission quantity

for bin 2, $e_{[emission],offcycle,bin2}$, is the value for CO₂-specific emission mass for a given pollutant of all the 300 second test intervals in bin 2 combined and

converted to a brake-specific value, as calculated for each measured pollutant using the following equation:

$$e_{[emissions],offcycle,bin2} = \frac{\sum_{i=1}^N m_{[emission],testinterval,i}}{\sum_{i=1}^N m_{CO_2,testinterval,i}} \cdot e_{CO_2,FTP}$$

Eq. 1036.530–5

Where:

i = an indexing variable that represents one 300 second test interval.

N = total number of 300 second test intervals in bin 2.

$m_{[emission],testinterval,i}$ = total emission mass for a given pollutant over the test interval i

in bin 2 as determined in paragraph (d)(2) of this section.

$m_{CO_2,testinterval,i}$ = total CO₂ emission mass over the test interval i in bin 2 as determined in paragraph (d)(2) of this section.

$e_{CO_2,FTP}$ = the engine's brake-specific CO₂ over the FTP duty cycle.

Example

$N = 15439$

$m_{NO_x1} = 0.546$ g

$m_{NO_x2} = 0.549$ g

$m_{NO_x3} = 0.556$ g

$m_{CO_2,1} = 10950.2$ g

$m_{CO_2,2} = 10961.3$ g

$m_{CO_2,3} = 10965.3$ g

$e_{CO_2,FTP} = 428.1$ g/hp-hr

$$e_{NO_x,offcycle,bin2} = \frac{(0.546 + 0.549 + 0.556 \dots + m_{NO_x,testinterval,15439})}{(10950.2 + 10961.3 + 10965.3 \dots + m_{CO_2,testinterval,15439})} \cdot 428.1$$

$$\epsilon_{\text{NOx,offcycle,bin2}} = 0.026 \text{ g/hp}\cdot\text{hr} = 26 \text{ mg/hp}\cdot\text{hr}$$

* * * * *

§§ 1036.535, 1036.540, and 1036.543

[Removed]

■ 94. Remove §§ 1036.535, 1036.540, and 1036.543.

■ 95. Revise and republish § 1036.545 to read as follows:

§ 1036.545 Powertrain testing.

This section describes the procedure to test a powertrain that includes an engine coupled with a transmission, drive axle, and hybrid components or any assembly with one or more of those hardware elements. The powertrain test procedure is one option for certifying hybrid powertrains to the engine standards in § 1036.104.

(a) *General test provisions.* The following provisions apply broadly for testing under this section:

(1) [Reserved]

(2) The procedures of 40 CFR part 1065 apply for testing in this section except as specified. This section uses engine parameters and variables that are consistent with 40 CFR part 1065.

(3) Powertrain testing depends on models to calculate certain parameters. You can use the detailed equations in this section to create your own models, or use the GEM HIL model contained within GEM Phase 2, Version 4.0 (incorporated by reference, see § 1036.810) to simulate vehicle hardware elements as follows:

(i) Create driveline and vehicle models that calculate the angular speed setpoint for the test cell dynamometer, $f_{\text{nref,dyno}}$, based on the torque

measurement location. Use the detailed equations in paragraph (f) of this section, the GEM HIL model's driveline and vehicle submodels, or a combination of the equations and the submodels. You may use the GEM HIL model's transmission submodel in paragraph (f) to simulate a transmission only if testing hybrid engines. For hybrid engines intended for vehicles with automatic transmissions, update the driver_in_gear signal within the driver interface block in the GEM HIL model with the transmission state (in-gear or idle) as a function of time as defined by the duty cycles in this part.

(ii) Create a driver model or use the GEM HIL model's driver submodel to simulate a human driver modulating the throttle and brake pedals to follow the test cycle as closely as possible.

(iii) Create a cycle-interpolation model or use the GEM HIL model's cycle submodel to interpolate the duty-cycles and feed the driver model the duty-cycle reference vehicle speed for each point in the duty-cycle.

(4) The powertrain test procedure in this section is designed to simulate operation of different vehicle configurations over specific duty cycles. See paragraph (j) of this section.

(5) [Reserved]

(6) For hybrid powertrains with no plug-in capability, correct for the net energy change of the energy storage device as described in 40 CFR 1066.501(a)(3). For plug-in hybrid electric powertrains, follow 40 CFR 1066.501(a)(3) to determine End-of-Test for charge-depleting operation.

(7) through (8) [Reserved]

(9) If you test a powertrain over the Low Load Cycle specified in § 1036.514, control and apply the electrical accessory loads. We recommend using a load bank connected directly to the powertrain's electrical system. You may instead use an alternator with dynamic electrical load control. Use good engineering judgment to account for the efficiency of the alternator or the efficiency of the powertrain to convert the mechanical energy to electrical energy.

(10) The following instruments are required with plug-in hybrid systems to determine required voltages and currents during testing and must be installed on the powertrain to measure these values during testing:

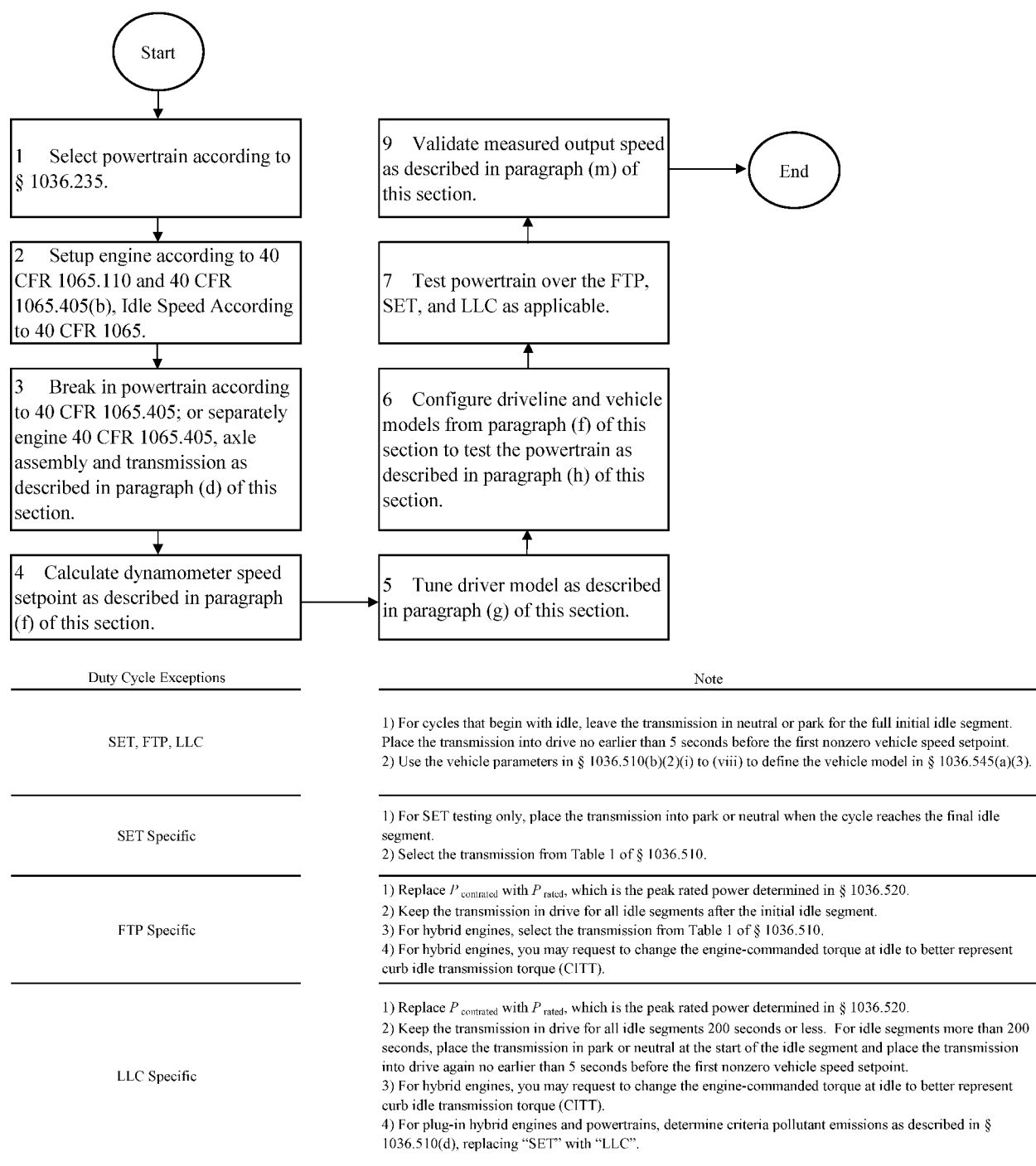
(i) Measure the voltage and current of the battery pack directly with a DC wideband power analyzer to determine power. Measure all current entering and leaving the battery pack. Do not measure voltage upstream of this measurement point. The maximum integration period for determining amp-hours is 0.05 seconds. The power analyzer must have an accuracy for measuring current and voltage of 1% of point or 0.3% of maximum, whichever is greater. The power analyzer must not be susceptible to offset errors while measuring current.

(ii) If safety considerations do not allow for measuring voltage, you may determine the voltage directly from the powertrain ECM.

(11) The following figure provides an overview of testing under this section:

BILLING CODE 6560-50-P

FIGURE 1 TO PARAGRAPH (a)(11) OF § 1036.545—OVERVIEW OF POWERTRAIN TESTING



BILLING CODE 6560–50–C

(b) *Test configuration.* Select a powertrain for testing as described in § 1036.235. Set up the engine according to 40 CFR 1065.110 and 1065.405(b). Set the engine's idle speed to warm idle speed defined in 40 CFR 1065.1001.

(1) The default test configuration consists of a powertrain with all components upstream of the axle. This involves connecting the powertrain's

output shaft directly to the dynamometer or to a gear box with a fixed gear ratio and measuring torque at the axle input shaft. You may instead set up the dynamometer to connect at the wheel hubs and measure torque at that location. The preceding sentence may apply if your powertrain configuration requires it, such as for hybrid powertrains or if you want to

represent the axle performance with powertrain test results. You may alternatively test the powertrain with a chassis dynamometer if you measure speed and torque at the powertrain's output shaft or wheel hubs.

(2) For testing hybrid engines, connect the engine's crankshaft directly to the dynamometer and measure torque at that location.

(c) *Powertrain temperatures during testing.* Cool the powertrain during testing so temperatures for oil, coolant, block, head, transmission, battery, and power electronics are within the manufacturer's expected ranges for normal operation. You may use electronic control module outputs to comply with this paragraph (c). You may use auxiliary coolers and fans.

(d) *Powertrain break in.* Break in the powertrain as a complete system using the engine break-in procedure in 40 CFR 1065.405(c), or take the following steps to break in the engine, axle assembly, and transmission separately as applicable: (1) Break in the engine according to 40 CFR 1065.405(c).

(2) Break in the axle assembly using good engineering judgment. Maintain gear oil temperature at or below 100 °C throughout the break-in period.

(3) Break in the transmission using good engineering judgment. Maintain transmission oil temperature at (87 to 93) °C for automatic transmissions and transmissions having more than two friction clutches, and at (77 to 83) °C for all other transmissions. You may ask us to approve a different range of transmission oil temperatures if you have data showing that it better represents in-use operation.

(e) *Dynamometer setup.* Set the dynamometer to operate in speed-control mode (or torque-control mode for hybrid engine testing at idle, including idle portions of transient duty cycles). Record data as described in 40 CFR 1065.202. Command and control the dynamometer speed at a minimum of 5 Hz, or 10 Hz for testing hybrid engines. Run the vehicle model to calculate the dynamometer setpoints at a rate of at least 100 Hz. If the dynamometer's command frequency is less than the vehicle model dynamometer setpoint frequency, subsample the calculated setpoints for commanding the dynamometer setpoints.

(f) *Driveline and vehicle model.* Use the GEM HIL model's driveline and vehicle submodels or the equations in this paragraph (f) to calculate the dynamometer speed setpoint, $f_{nref,dyno}$, based on the torque measurement location. For all powertrains, configure GEM with the accessory load set to zero. For hybrid engines, configure GEM with the applicable accessory load as specified in §§ 1036.514 and 1036.525. For all powertrains and hybrid engines, configure GEM with the tire slip model disabled.

(1) *Driveline model with a transmission in hardware.* For testing with torque measurement at the axle input shaft or wheel hubs, calculate, $f_{nref,dyno}$, using the GEM HIL model's driveline submodel or the following equation:

$$f_{nrefi,dyno} = \frac{k_{a[speed]} \cdot v_{refi}}{2 \cdot \pi \cdot r_{[speed]}}$$

Eq. 1036.545–1

Where:

$k_{a[speed]}$ = drive axle ratio as determined in paragraph (h) of this section. Set $k_{a[speed]}$ equal to 1.0 if torque is measured at the wheel hubs.

v_{refi} = simulated vehicle reference speed as calculated in paragraph (f)(3) of this section.

$r_{[speed]}$ = tire radius as determined in paragraph (h) of this section.

(2) *Driveline model with a simulated transmission.* For testing with the torque measurement at the engine's crankshaft, $f_{nref,dyno}$ is the dynamometer target speed from the GEM HIL model's transmission submodel. You may request our approval to change the transmission submodel, as long as the changes do not affect the gear selection logic. Before testing, initialize the transmission model with the engine's measured torque curve and the applicable steady-state fuel map from the GEM HIL model. Configure the torque converter to simulate neutral idle when using this procedure to perform the Supplemental

Emission Test (SET) testing under § 1036.510. You may change engine commanded torque at idle to better represent CITT for transient testing under § 1036.512. You may change the simulated engine inertia to match the inertia of the engine under test. We will evaluate your requests under this paragraph (f)(2) based on your demonstration that the adjusted testing better represents in-use operation.

(i) The transmission submodel needs the following model inputs:

(A) Torque measured at the engine's crankshaft.

(B) Engine estimated torque determined from the electronic control module or by converting the instantaneous operator demand to an instantaneous torque in N-m.

(C) Dynamometer mode when idling (speed-control or torque-control).

(D) Measured engine speed when idling.

(E) Transmission output angular speed, $f_{ni,transmission}$, calculated as follows:

$$f_{ni,transmission} = \frac{k_{a[speed]} \cdot v_{refi}}{2 \cdot \pi \cdot r_{[speed]}}$$

Eq. 1036.545–2

Where:

$k_{a[speed]}$ = drive axle ratio as determined in paragraph (h) of this section.

v_{refi} = simulated vehicle reference speed as calculated in paragraph (f)(3) of this section.

$r_{[speed]}$ = tire radius as determined in paragraph (h) of this section.

(ii) The transmission submodel generates the following model outputs:

(A) Dynamometer target speed.

(B) Dynamometer idle load.

(C) Transmission engine load limit.

(D) Engine speed target.

(3) *Vehicle model.* Calculate the simulated vehicle reference speed, v_{refi} , using the GEM HIL model's vehicle submodel or the equations in this paragraph (f)(3):

$$v_{refi} = \left(\frac{k_a \cdot T_{i-1}}{r} \cdot (Eff_{axle}) - \left(M \cdot g \cdot C_{rr} \cdot \cos(\text{atan}(G_{i-1})) + \frac{\rho \cdot C_d A}{2} \cdot v_{ref,i-1}^2 \right) - F_{brake,i-1} - F_{grade,i-1} \right) \cdot \frac{\Delta t_{i-1}}{M + M_{rotating}} + v_{ref,i-1}$$

Eq. 1036.545–3

Where:

i = a time-based counter corresponding to each measurement during the sampling

period. Let $v_{ref1} = 0$; start calculations at

$i = 2$. A 10-minute sampling period will generally involve 60,000 measurements. T = instantaneous measured torque at the axle input, measured at the wheel hubs, or simulated by the GEM HIL model's transmission submodel. For configurations with multiple torque measurements, such as when measuring torque at the wheel hubs, T is the sum of all torque measurements.

Eff_{axle} = axle efficiency. Use $Eff_{axle} = 0.955$ for $T \geq 0$, and use $Eff_{axle} = 1/0.955$ for $T < 0$. Use $Eff_{axle} = 1.0$ if torque is measured at the wheel hubs.

M = vehicle mass for a vehicle class as determined in paragraph (h) of this section.

g = gravitational constant = 9.80665 m/s².

C_{rr} = coefficient of rolling resistance for a vehicle class as determined in paragraph (h) of this section.

G_{i-1} = the percent grade interpolated at distance, D_{i-1} , from the duty cycle in § 1036.510 and appendix B to this part, corresponding to measurement ($i-1$).

$$D_{i-1} = \sum_{i=1}^N (v_{ref,i-1} \cdot \Delta t_{i-1})$$

Eq. 1036.545–4

ρ = air density at reference conditions. Use $\rho = 1.1845$ kg/m³.

C_{dA} = drag area for a vehicle class as determined in paragraph (h) of this section.

$F_{brake,i-1}$ = instantaneous braking force applied by the driver model.

$$F_{grade,i-1} = M \cdot g \cdot \sin(\text{atan}(G_{i-1}))$$

Eq. 1036.545–5

Δt = the time interval between measurements. For example, at 100 Hz, $\Delta t = 0.0100$ seconds.

$M_{rotating}$ = inertial mass of rotating components. Let $M_{rotating} = 340$ kg for Light HDE or Medium HDE, and 1,021 kg for Heavy HDE.

(g) *Driver model*. Use the GEM HIL model's driver submodel or design a driver model to simulate a human driver modulating the throttle and brake pedals. In either case, tune the model to follow the test cycle as closely as possible meeting the following specifications:

(1) The driver model must meet the following speed requirements:

(i) [Reserved]

(ii) For operation over the SET as defined § 1036.510, the Federal Test Procedure (FTP) as defined in § 1036.512, and the Low Load Cycle (LLC) as defined in § 1036.514, the speed requirements described in 40 CFR 1066.425(b) and (c).

(iii) The exceptions in 40 CFR 1066.425(b)(4) apply to the SET, FTP, and LLC.

(iv) If the speeds do not conform to these criteria, the test is not valid and must be repeated.

(2) Send a brake signal when operator demand is zero and vehicle speed is

greater than the reference vehicle speed from the test cycle. Include a delay before changing the brake signal to prevent dithering, consistent with good engineering judgment.

(3) Allow braking only if operator demand is zero.

(h)–(i) [Reserved]

(j) *Duty cycles to evaluate*. Operate the powertrain over each of the duty cycles specified in §§ 1036.510, 1036.512, and 1036.514 as applicable.

(k)–(l) [Reserved]

(m) *Measured output speed validation*. For each test point, validate the measured output speed with the corresponding reference values. If speed is measured at more than one location, the measurements at each location must meet validation requirements. If the range of reference speed is less than 10 percent of the mean reference speed, you need to meet only the standard error of the estimate in table 4 to this paragraph (m). You may delete points when the vehicle is stopped. If your speed measurement is not at the location of f_{nref} , correct your measured speed using the constant speed ratio between the two locations. Apply cycle-validation criteria for each separate transient or highway cruise cycle based on the following parameters:

TABLE 4 TO PARAGRAPH (m) OF § 1036.545—CYCLE-VALIDATION CRITERIA

Parameter ^a	Speed control
Slope, a_1	$0.990 \leq a_1 \leq 1.010$.
Absolute value of intercept, $|a_0|$ .....	$\leq 2.0\%$ of maximum f_{nref} speed.
Standard error of the estimate, SEE	$\leq 2.0\%$ of maximum f_{nref} speed.
Coefficient of determination, r^2	≥ 0.990 .

^a Determine values for specified parameters as described in 40 CFR 1065.514(e) by comparing measured and reference values for $f_{nref,dyno}$.

§ 1036.550 [Removed]

■ 96. Remove § 1036.550.

■ 97. Amend § 1036.580 by revising the introductory text and paragraph (c) to read as follows:

§ 1036.580 Infrequently regenerating aftertreatment devices.

For engines using aftertreatment technology with infrequent regeneration events that may occur during testing, take one of the following approaches to account for the emission impact of regeneration on criteria pollutant emissions:

* * * * *

(c) You may choose to make no adjustments to measured emission results if you determine that regeneration does not significantly affect emission levels for an engine family (or configuration) or if it is not practical to

identify when regeneration occurs. You may omit adjustment factors under this paragraph (c) individual pollutants under this paragraph (c) as appropriate. If you choose not to make adjustments under paragraph (a) or (b) of this section, your engines must meet emission standards for all testing, without regard to regeneration.

* * * * *

■ 98. Amend § 1036.605 by revising paragraphs (b) and (g) to read as follows:

§ 1036.605 Alternate emission standards for engines used in specialty vehicles.

* * * * *

(b) Compression-ignition engines must be of a configuration that is identical to one that is certified under 40 CFR part 1039, and must be certified with a family emission limit for PM of 0.020 g/kW-hr using the same duty

cycles that apply under 40 CFR part 1039.

* * * * *

(g) Engines certified under this section may not generate or use emission credits under this part or under 40 CFR part 1039.

§§ 1036.610, 1036.615, 1036.620, 1036.625, 1036.630, and 1036.635 [Removed]

■ 99. Remove §§ 1036.610, 1036.615, 1036.620, 1036.625, 1036.630, 1036.635.

■ 100. Revise and republish § 1036.701 to read as follows:

§ 1036.701 General provisions.

(a) You may average, bank, and trade (ABT) emission credits for purposes of certification as described in this subpart and in subpart B of this part to show compliance with the standards of §§ 1036.104. Participation in this

program is voluntary. Note that certification to NO_x standards in § 1036.104 is based on a family emission limit (FEL).

(b) The definitions of subpart I of this part apply to this subpart in addition to the following definitions:

(1) *Actual emission credits* means emission credits you have generated that we have verified by reviewing your final report.

(2) *Averaging set* means a set of engines in which emission credits may be exchanged. See § 1036.740.

(3) *Broker* means any entity that facilitates a trade of emission credits between a buyer and seller.

(4) *Buyer* means the entity that receives emission credits as a result of a trade.

(5) *Reserved emission credits* means emission credits you have generated that we have not yet verified by reviewing your final report.

(6) *Seller* means the entity that provides emission credits during a trade.

(7) *Standard* means the emission standard that applies under subpart B of this part for engines not participating in the ABT program of this subpart.

(8) *Trade* means to exchange emission credits, either as a buyer or seller.

(c) Emission credits may be exchanged only within an averaging set, except as specified in § 1036.740.

(d) You may not use emission credits generated under this subpart to offset any emissions that exceed an FEL or standard. This paragraph (d) applies for all testing, including certification testing, in-use testing, selective enforcement audits, and other production-line testing. However, if emissions from an engine exceed an FEL or standard (for example, during a selective enforcement audit), you may use emission credits to recertify the engine family with a higher FEL that applies only to future production.

(e) You may use either of the following approaches to retire or forego emission credits:

(1) You may retire emission credits generated from any number of your engines. This may be considered donating emission credits to the environment. Identify any such credits in the reports described in § 1036.730. Engines must comply with the applicable FELs even if you donate or sell the corresponding emission credits. Donated credits may no longer be used by anyone to demonstrate compliance with any EPA emission standards.

(2) You may certify an engine family using an FEL below the emission standard as described in this part and choose not to generate emission credits

for that family. If you do this, you do not need to calculate emission credits for those engine families, and you do not need to submit or keep the associated records described in this subpart for that family.

(f) Emission credits may be used in the model year they are generated. Surplus emission credits may be banked for future model years.

(g) You may increase or decrease an FEL during the model year by amending your application for certification under § 1036.225. The new FEL may apply only to engines you have not already introduced into commerce.

(h)–(j) [Reserved]

(k) Engine families you certify with a nonconformance penalty under 40 CFR part 86, subpart L, may not generate emission credits.

■ 101. Revise and republish § 1036.705 to read as follows:

§ 1036.705 Generating and calculating emission credits.

(a) The provisions of this section apply separately for calculating NO_x emission credits.

(b) For each participating family, calculate positive or negative emission credits relative to the otherwise applicable emission standard. Calculate positive emission credits for a family that has an FEL below the standard. Calculate negative emission credits for a family that has an FEL above the standard. Sum your positive and negative credits for the model year before rounding. Calculate emission credits to the nearest megagram (Mg) for each family using the following equation:

$$\text{Emission credits (Mg)} = (\text{Std} - \text{FL}) \cdot \text{CF} \cdot \text{Volume} \cdot \text{UL} \cdot c$$

Eq. 1036.705–1

Where:

Std = the emission standard, in (mg NO_x)/hp-hr that applies under subpart B of this part for engines not participating in the ABT program of this subpart (the “otherwise applicable standard”).

FL = the engine family’s FEL, in mg/hp-hr, rounded to the same number of decimal places as the emission standard.

CF = a transient cycle conversion factor (hp-hr/mile), calculated by dividing the total (integrated) horsepower-hour over the applicable duty cycle by 6.3 miles for engines subject to spark-ignition standards and 6.5 miles for engines subject to compression-ignition standards. This represents the average work performed over the duty cycle.

Volume = the number of engines eligible to participate in the averaging, banking, and trading program within the given engine family during the model year, as described in paragraph (c) of this section.

UL = the useful life for the standard that applies for a given primary intended service class, in miles.

$$c = 10^{-9}.$$

Example for Model Year 2028 Heavy HDE Generating NO_x credits

Std = 35 mg/hp-hr

FEL = 20 mg/hp-hr

CF = 9.78 hp-hr/mile

Volume = 15,342

UL = 650,000 miles

$$c = 10^{-6}$$

$$\text{Emission credits} = (35 - 20) \cdot 9.78 \cdot 15,342 \cdot 650,000 \cdot 10^{-9}$$

$$\text{Emission credits} = 1,463 \text{ Mg}$$

(c) Compliance with the requirements of this subpart is determined at the end of the model year by calculating emission credits based on actual production volumes, excluding the following engines:

(1) Engines that you do not certify to the standards of this part because they are permanently exempted under subpart G of this part or under 40 CFR part 1068.

(2) Exported engines.

(3) Engines not subject to the requirements of this part, such as those excluded under § 1036.5.

(4) Engines certified to state emission standards that are different than the emission standards referenced in this section, and intended for sale in a state that has adopted those emission standards.

(5) Any other engines if we indicate elsewhere in this part that they are not to be included in the calculations of this subpart.

■ 102. Revise § 1036.710 to read as follows:

§ 1036.710 Averaging.

(a) Averaging is the exchange of emission credits among your engine families. You may average emission credits only within the same averaging set, except as specified in § 1036.740.

(b) You may certify one or more engine families to an FEL above the applicable standard, subject to any applicable FEL caps and other the provisions in subpart B of this part, if you show in your application for certification that your projected balance of all emission-credit transactions in that model year is greater than or equal to zero.

(c) If you certify an engine family to an FEL that exceeds the otherwise applicable standard, you must obtain enough emission credits to offset the engine family’s deficit by the due date for the final report required in § 1036.730. The emission credits used to address the deficit may come from your other engine families that generate emission credits in the same model

year, from emission credits you have banked, or from emission credits you obtain through trading.

■ 103. Amend § 1036.720 by revising paragraph (c) to read as follows:

§ 1036.720 Trading.

* * * * *

(c) If a negative emission credit balance results from a transaction, both the buyer and seller are liable, except in cases we deem to involve fraud. See § 1036.255(e) for cases involving fraud. We may void the certificates of all engine families participating in a trade that results in a manufacturer having a negative balance of emission credits.

■ 104. Revise § 1036.725 to read as follows:

§ 1036.725 Required information for certification.

(a) You must declare in your application for certification your intent to use the provisions of this subpart for each engine family that will be certified using the ABT program. You must also declare the FEL you select for the engine family for each pollutant for which you are using the ABT program. Your FELs must comply with the specifications of subpart B of this part, including the FEL caps.

(b) Include the following in your application for certification:

(1) A statement that, to the best of your belief, you will not have a negative balance of emission credits for any averaging set when all emission credits are calculated at the end of the year.

(2) Calculations of projected emission credits (positive or negative) based on projected production volumes as described in § 1036.705(c). We may require you to include similar calculations from your other engine families to project your net credit balances for the model year. If you project negative emission credits for a family, state the source of positive emission credits you expect to use to offset the negative emission credits.

■ 105. Amend § 1036.730 by revising paragraphs (b)(3) and (4), (c)(1), and (f)(1) to read as follows:

§ 1036.730 ABT reports.

* * * * *

(b) * * *

(3) The FEL for each pollutant. If you change the FEL after the start of production, identify the date that you started using the new FEL and/or give the engine identification number for the first engine covered by the new FEL. In this case, identify each applicable FEL and calculate the positive or negative emission credits as specified in § 1036.225(f).

(4) The projected and actual production volumes for calculating emission credits for the model year. If you changed an FEL during the model year, identify the actual production volume associated with each FEL.

* * * * *

(c) * * *

(1) Show that your net balance of emission credits from all your participating engine families in each averaging set in the applicable model year is not negative. Your credit tracking must account for the limitation on credit life under § 1036.740(d).

* * * * *

(f) * * *

(1) If you notify us by the deadline for submitting the final report that errors mistakenly decreased your balance of emission credits, you may correct the errors and recalculate the balance of emission credits.

* * * * *

■ 106. Amend § 1036.735 by revising paragraph (d) to read as follows:

§ 1036.735 Recordkeeping.

* * * * *

(d) Keep appropriate records to document production volumes of engines that generate or use emission credits under the ABT program. For example, keep available records of the engine identification number (usually the serial number) for each engine you produce that generates or uses emission credits. You may identify these numbers as a range. If you change the FEL after the start of production, identify the date you started using each FEL and the range of engine identification numbers associated with each FEL. You must also identify the purchaser and destination for each engine you produce to the extent this information is available.

* * * * *

■ 107. Amend § 1036.740 by removing and reserving paragraphs (b) and (c) and revising paragraph (d) to read as follows:

§ 1036.740 Restrictions for using emission credits.

* * * * *

(d) *NO_x* credit life. *NO_x* credits may be used only for five model years after the year in which they are generated. For example, credits you generate in model year 2027 may be used to demonstrate compliance with emission standards only through model year 2032.

* * * * *

§ 1036.745 [Removed]

■ 108. Remove § 1036.745.

■ 109. Amend § 1036.750 by revising paragraph (b) to read as follows:

§ 1036.750 Consequences for noncompliance.

* * * * *

(b) You may certify your engine family to an FEL above an applicable standard based on a projection that you will have enough emission credits to offset the deficit for the engine family.

* * * * *

§ 1036.755 [Removed]

■ 110. Remove § 1036.755.

■ 111. Revise and republish § 1036.801 to read as follows:

§ 1036.801 Definitions.

The following definitions apply to this part. The definitions apply to all subparts unless we note otherwise. All undefined terms have the meaning the Act gives to them. The definitions follow:

Act means the Clean Air Act, as amended, 42 U.S.C. 7401–7671q.

Adjustable parameter has the meaning given in 40 CFR 1068.50.

Aftertreatment means relating to a catalytic converter, particulate filter, or any other system, component, or technology mounted downstream of the exhaust valve (or exhaust port) whose design function is to decrease emissions in the engine exhaust before it is exhausted to the environment. Exhaust gas recirculation (EGR) and turbochargers are not aftertreatment.

Aircraft means any vehicle capable of sustained air travel more than 100 feet above the ground.

Alcohol-fueled engine mean an engine that is designed to run using an alcohol fuel. For purposes of this definition, alcohol fuels do not include fuels with a nominal alcohol content below 25 percent by volume.

Automated manual transmission (AMT) means a transmission that operates mechanically similar to a manual transmission, except that an automated clutch actuator controlled by the onboard computer disengages and engages the drivetrain instead of a human driver. An automated manual transmission does not include a torque converter or a clutch pedal controllable by the driver.

Automatic transmission (AT) means a transmission with a torque converter (or equivalent) that uses computerize or other internal controls to shift gears in response to a single driver input for controlling vehicle speed. Note that automatic manual transmissions are not automatic transmissions because they do not include torque converters.

Auxiliary emission control device means any element of design that senses

temperature, motive speed, engine speed (r/min), transmission gear, or any other parameter for the purpose of activating, modulating, delaying, or deactivating the operation of any part of the emission control system.

Averaging set has the meaning given in § 1036.740.

Axle ratio or Drive axle ratio, k_a , means the dimensionless number representing the angular speed of the transmission output shaft divided by the angular speed of the drive axle.

Calibration means the set of specifications and tolerances specific to a particular design, version, or application of a component or assembly capable of functionally describing its operation over its working range.

Carbon-containing fuel has the meaning given in 40 CFR 1065.1001.

Carryover means relating to certification based on emission data generated from an earlier model year as described in § 1036.235(d).

Certification means relating to the process of obtaining a certificate of conformity for an engine family that complies with the emission standards and requirements in this part.

Certified emission level means the highest deteriorated emission level in an engine family for a given pollutant from the applicable transient and/or steady-state testing, rounded to the same number of decimal places as the applicable standard.

Charge-depleting has the meaning given in 40 CFR 1066.1001.

Charge-sustaining has the meaning given in 40 CFR 1066.1001.

Complete vehicle means a vehicle meeting the definition of complete vehicle in 40 CFR 1037.801 when it is first sold as a vehicle. For example, where a vehicle manufacturer sells an incomplete vehicle to a secondary vehicle manufacturer, the vehicle is not a complete vehicle under this part, even after its final assembly.

Compression-ignition means relating to a type of reciprocating, internal-combustion engine that is not a spark-ignition engine. Note that § 1036.1 also deems gas turbine engines and other engines to be compression-ignition engines.

Crankcase emissions means airborne substances emitted to the atmosphere from any part of the engine crankcase's ventilation or lubrication systems. The crankcase is the housing for the crankshaft and other related internal parts.

Critical emission-related component has the meaning given in 40 CFR 1068.30.

Defeat device has the meaning given in § 1036.115(h).

Designated Compliance Officer means one of the following:

(1) For engines subject to compression-ignition standards, *Designated Compliance Officer* means Director, Diesel Engine Compliance Center, U.S. Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; complianceinfo@epa.gov; www.epa.gov/ve-certification.

(2) For engines subject to spark-ignition standards, *Designated Compliance Officer* means Director, Gasoline Engine Compliance Center, U.S. Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; complianceinfo@epa.gov; www.epa.gov/ve-certification.

Deteriorated emission level means the emission level that results from applying the appropriate deterioration factor to the official emission result of the emission-data engine. Note that where no deterioration factor applies, references in this part to the *deteriorated emission level* mean the official emission result.

Deterioration factor means the relationship between emissions at the end of useful life (or point of highest emissions if it occurs before the end of useful life) and emissions at the low-hour/low-mileage point, expressed in one of the following ways:

(1) For multiplicative deterioration factors, the ratio of emissions at the end of useful life (or point of highest emissions) to emissions at the low-hour point.

(2) For additive deterioration factors, the difference between emissions at the end of useful life (or point of highest emissions) and emissions at the low-hour point.

Diesel exhaust fluid (DEF) means a liquid reducing agent (other than the engine fuel) used in conjunction with selective catalytic reduction to reduce NO_x emissions. *Diesel exhaust fluid* is generally understood to be an aqueous solution of urea conforming to the specifications of ISO 22241.

Drive idle means idle operation during which the vehicle operator remains in the vehicle cab, as evidenced by engaging the brake or clutch pedals, or by other indicators we approve.

Dual-fuel means relating to an engine designed for operation on two different types of fuel but not on a continuous mixture of those fuels (see § 1036.601(d)). For purposes of this part, such an engine remains a dual-fuel engine even if it is designed for operation on three or more different fuels.

Electronic control module (ECM) means an engine's electronic device that

uses data from engine sensors to control engine parameters.

Emergency vehicle means a vehicle that meets one of the following criteria:

(1) It is an ambulance or a fire truck.

(2) It is a vehicle that we have determined will likely be used in emergency situations where emission control function or malfunction may cause a significant risk to human life. For example, we would consider a truck that is certain to be retrofitted with a slip-on firefighting module to become an emergency vehicle, even though it was not initially designed to be a fire truck. Also, a mobile command center that is unable to manually regenerate its DPF while on duty could be an emergency vehicle. In making this determination, we may consider any factor that has an effect on the totality of the actual risk to human life. For example, we may consider how frequently a vehicle will be used in emergency situations or how likely it is that the emission controls will cause a significant risk to human life when the vehicle is used in emergency situations. We would not consider the truck in the example above to be an emergency vehicle if there is merely a possibility (rather than a certainty) that it will be retrofitted with a slip-on firefighting module.

Emission control system means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from an engine.

Emission-data engine means an engine that is tested for certification. This includes engines tested to establish deterioration factors.

Emission-related component has the meaning given in 40 CFR part 1068, appendix A.

Emission-related maintenance means maintenance that substantially affects emissions or is likely to substantially affect emission deterioration.

Engine configuration means a unique combination of engine hardware and calibration (related to the emission standards) within an engine family, which would include hybrid components for engines certified as hybrid engines and hybrid powertrains. Engines within a single engine configuration differ only with respect to normal production variability or factors unrelated to compliance with emission standards.

Engine family has the meaning given in § 1036.230.

Excluded means relating to engines that are not subject to some or all of the requirements of this part as follows:

(1) An engine that has been determined not to be a heavy-duty engine is excluded from this part.

(2) Certain heavy-duty engines are excluded from the requirements of this part under § 1036.5.

(3) Specific regulatory provisions of this part may exclude a heavy-duty engine generally subject to this part from one or more specific standards or requirements of this part.

Exempted has the meaning given in 40 CFR 1068.30.

Exhaust gas recirculation means a technology that reduces emissions by routing exhaust gases that had been exhausted from the combustion chamber(s) back into the engine to be mixed with incoming air before or during combustion. The use of valve timing to increase the amount of residual exhaust gas in the combustion chamber(s) that is mixed with incoming air before or during combustion is not considered exhaust gas recirculation for the purposes of this part.

Family emission limit (FEL) means a NO_x emission level declared by the manufacturer to serve in place of an otherwise applicable emission standard under the ABT program in subpart H of this part. The FEL serves as the emission standard for the engine family with respect to all required testing.

Federal Test Procedure (FTP) means the applicable transient duty cycle described in § 1036.512 designed to measure exhaust emissions during urban driving.

Final drive ratio, k_d , means the dimensionless number representing the angular speed of the transmission input shaft divided by the angular speed of the drive axle when the vehicle is operating in its highest available gear. The *final drive ratio* is the transmission gear ratio (in the highest available gear) multiplied by the drive axle ratio.

Flexible-fuel means relating to an engine designed for operation on any mixture of two or more different types of fuels (see § 1036.601(d)).

Fuel type means a general category of fuels such as diesel fuel, gasoline, or natural gas. There can be multiple grades within a single fuel type, such as premium gasoline, regular gasoline, or gasoline with 10 percent ethanol.

Gear ratio or Transmission gear ratio, k_g , means the dimensionless number representing the angular speed of the transmission's input shaft divided by the angular speed of the transmission's output shaft when the transmission is operating in a specific gear.

Good engineering judgment has the meaning given in 40 CFR 1068.30. See 40 CFR 1068.5 for the administrative process we use to evaluate good engineering judgment.

Greenhouse gas Emissions Model (GEM) means the GEM simulation tool referenced in § 1036.810.

Gross vehicle weight rating (GVWR) means the value specified by the vehicle manufacturer as the maximum design loaded weight of a single vehicle, consistent with good engineering judgment.

Heavy-duty engine means any engine which the engine manufacturer could reasonably expect to be used for motive power in a heavy-duty vehicle. For purposes of this definition in this part, the term "engine" includes internal combustion engines and other devices that convert chemical fuel into motive power. For example, a gas turbine used in a heavy-duty vehicle is a heavy-duty engine.

Heavy-duty vehicle means any motor vehicle above 8,500 pounds GVWR. An incomplete vehicle is also a heavy-duty vehicle if it has a curb weight above 6,000 pounds or a basic vehicle frontal area greater than 45 square feet. *Curb weight* and *basic vehicle frontal area* have the meaning given in 40 CFR 86.1803–01.

Hybrid means relating to an engine or powertrain that includes a Rechargeable Energy Storage System. Hybrid engines store and recover energy in a way that is integral to the engine or otherwise upstream of the vehicle's transmission. Examples of hybrid engines include engines with hybrid components connected to the front end of the engine (P0), connected to the crankshaft before the clutch (P1), or connected between the clutch and the transmission where the clutch upstream of the hybrid feature is in addition to the transmission clutch or clutches (P2). Engine-based systems that recover kinetic energy to power an electric heater in the aftertreatment are themselves not sufficient to qualify as a hybrid engine. The provisions in this part that apply for hybrid powertrains apply equally for hybrid engines, except as specified. Note that certain provisions in this part treat hybrid powertrains intended for vehicles that include regenerative braking different than those intended for vehicles that do not include regenerative braking. The definition of hybrid includes plug-in hybrid electric powertrains.

Hydrocarbon (HC) has the meaning given in 40 CFR 1065.1001.

Identification number means a unique specification (for example, a model number/serial number combination) that allows someone to distinguish a particular engine from other similar engines.

Incomplete vehicle means a vehicle meeting the definition of incomplete

vehicle in 40 CFR 1037.801 when it is first sold (or otherwise delivered to another entity) as a vehicle.

Liquefied petroleum gas (LPG) means a liquid hydrocarbon fuel that is stored under pressure and is composed primarily of nonmethane compounds that are gases at atmospheric conditions. Note that, although this commercial term includes the word "petroleum", LPG is not considered to be a petroleum fuel under the definitions of this section.

Low-hour means relating to an engine that has stabilized emissions and represents the undeteriorated emission level. This would generally involve less than 300 hours of operation for engines with NO_x aftertreatment and 125 hours of operation for other engines.

Manual transmission (MT) means a transmission that requires the driver to shift the gears and manually engage and disengage the clutch.

Manufacture means the physical and engineering process of designing, constructing, and/or assembling a heavy-duty engine or a heavy-duty vehicle.

Manufacturer has the meaning given in 40 CFR 1068.30.

Medium-duty passenger vehicle has the meaning given in 40 CFR 86.1803.

Model year means the manufacturer's annual new model production period, except as restricted under this definition. It must include January 1 of the calendar year for which the model year is named, may not begin before January 2 of the previous calendar year, and it must end by December 31 of the named calendar year. Manufacturers may not adjust model years to circumvent or delay compliance with emission standards or to avoid the obligation to certify annually.

Motorcoach means a heavy-duty vehicle designed for carrying 30 or more passengers over long distances. Such vehicles are characterized by row seating, rest rooms, and large luggage compartments, and facilities for stowing carry-on luggage.

Motor vehicle has the meaning given in 40 CFR 85.1703.

Natural gas means a fuel whose primary constituent is methane.

Neat has the meaning given in 40 CFR 1065.1001.

New motor vehicle engine has the meaning given in the Act. This generally means a motor vehicle engine meeting any of the following:

(1) A motor vehicle engine for which the ultimate purchaser has never received the equitable or legal title is a *new motor vehicle engine*. This kind of engine might commonly be thought of as "brand new" although a *new motor*

vehicle engine may include previously used parts. Under this definition, the engine is new from the time it is produced until the ultimate purchaser receives the title or places it into service, whichever comes first.

(2) An imported motor vehicle engine is a *new motor vehicle engine* if it was originally built on or after January 1, 1970.

(3) Any motor vehicle engine installed in a new motor vehicle.

Noncompliant engine means an engine that was originally covered by a certificate of conformity, but is not in the certified configuration or otherwise does not comply with the conditions of the certificate.

Nonconforming engine means an engine not covered by a certificate of conformity that would otherwise be subject to emission standards.

Nonmethane hydrocarbon (NMHC) means the sum of all hydrocarbon species except methane, as measured according to 40 CFR part 1065.

Nonmethane hydrocarbon equivalent (NMHCE) has the meaning given in 40 CFR 1065.1001.

Nonmethane nonethane hydrocarbon equivalent (NMNEHC) has the meaning given in 40 CFR 1065.1001.

Official emission result means the measured emission rate for an emission-data engine on a given duty cycle before the application of any deterioration factor, but after the applicability of any required regeneration or other adjustment factors.

Owners manual means a document or collection of documents prepared by the engine or vehicle manufacturer for the owner or operator to describe appropriate engine maintenance, applicable warranties, and any other information related to operating or keeping the engine. The owners manual is typically provided to the ultimate purchaser at the time of sale. The owners manual may be in paper or electronic format.

Oxides of nitrogen has the meaning given in 40 CFR 1065.1001.

Percent has the meaning given in 40 CFR 1065.1001. Note that this means percentages identified in this part are assumed to be infinitely precise without regard to the number of significant figures. For example, one percent of 1,493 is 14.93.

Placed into service means put into initial use for its intended purpose, excluding incidental use by the manufacturer or a dealer.

Preliminary approval means approval granted by an authorized EPA representative prior to submission of an application for certification, consistent with the provisions of § 1036.210.

Primary intended service class has the meaning given in § 1036.140.

Rechargeable Energy Storage System (RESS) has the meaning given in 40 CFR 1065.1001.

Relating to as used in this section means relating to something in a specific, direct manner. This expression is used in this section only to define terms as adjectives and not to broaden the meaning of the terms.

Revoke has the meaning given in 40 CFR 1068.30.

Round has the meaning given in 40 CFR 1065.1001.

Sample means the collection of engines selected from the population of an engine family for emission testing. This may include testing for certification, production-line testing, or in-use testing.

Scheduled maintenance means adjusting, removing, disassembling, cleaning, or replacing components or systems periodically to keep a part or system from failing, malfunctioning, or wearing prematurely.

Small manufacturer means a manufacturer meeting the criteria specified in 13 CFR 121.201. The employee and revenue limits apply to the total number of employees and total revenue together for all affiliated companies (as defined in 40 CFR 1068.30). Note that manufacturers with low production volumes may or may not be “small manufacturers”.

Spark-ignition means relating to a gasoline-fueled engine or any other type of engine with a spark plug (or other sparking device) and with operating characteristics significantly similar to the theoretical Otto combustion cycle. Spark-ignition engines usually use a throttle to regulate intake air flow to control power during normal operation.

Stop-start means a vehicle technology that automatically turns the engine off when the vehicle is stopped.

Steady-state has the meaning given in 40 CFR 1065.1001. This includes idle testing where engine speed and load are held at a finite set of nominally constant values.

Suspend has the meaning given in 40 CFR 1068.30.

Test engine means an engine in a sample.

Ultimate purchaser means, with respect to any new engine or vehicle, the first person who in good faith purchases such new engine or vehicle for purposes other than resale.

United States has the meaning given in 40 CFR 1068.30.

Upcoming model year means for an engine family the model year after the one currently in production.

U.S.-directed production volume means the number of engines, subject to

the requirements of this part, produced by a manufacturer for which the manufacturer has a reasonable assurance that sale was or will be made to ultimate purchasers in the United States.

Vehicle has the meaning given in 40 CFR 1037.801.

Void has the meaning given in 40 CFR 1068.30.

We (us, our) means the Administrator of the Environmental Protection Agency and any authorized representatives.

§ 1036.805 [Amended]

■ 112. Amend § 1036.805 by revising Table 5 to Paragraph (e) to remove entries for “FCL”, “Heavy HDV”, “Light HDV”, and “Medium HDV”.

§ 1036.810 [Amended]

■ 113. Amend § 1036.810 by removing and reserving paragraphs (a)(2) and (3).

■ 114. Amend § 1036.815 by revising paragraph (b) to read as follows:

§ 1036.815 Confidential information.

* * * * *

(b) Emission data or information that is publicly available cannot be treated as confidential business information as described in 40 CFR 1068.11.

Appendix C to Part 1036 [Removed]

■ 115. Remove appendix C to part 1036.

PART 1037—CONTROL OF EMISSIONS FROM NEW HEAVY-DUTY MOTOR VEHICLES

■ 116. The authority citation for part 1036 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

§ 1037.5 [Amended]

■ 117. Amend § 1037.5 by removing and reserving paragraphs (c) and (d).

■ 118. Amend § 1037.10 by revising paragraph (b) and removing and reserving paragraphs (d) through (f) and (h). The revision reads as follows:

§ 1037.10 How is this part organized?

* * * * *

(b) Subpart B of this part describes the emission standards and other requirements that must be met to certify vehicles under this part.

* * * * *

■ 119. Amend § 1037.15 by revising paragraph (a) to read as follows:

§ 1037.15 Do any other regulation parts apply to me?

(a) Parts 1065 and 1066 of this chapter describe procedures and equipment specifications for testing engines and vehicles to measure exhaust emissions.

* * * * *

§ 1037.101 [Amended]

- 120. Amend § 1037.101 by removing and reserving paragraphs (a)(2) and (b)(2).
- 121. Revise and republish § 1037.102 to read as follows:

§ 1037.102 Criteria pollutant exhaust emission standards—NO_x, HC, PM, and CO.

(a) Engines installed in heavy-duty vehicles are subject to criteria pollutant standards for NO_x, HC, PM, and CO under 40 CFR part 86 through model year 2026 and 40 CFR part 1036 for model years 2027 and later.

(1) The following vehicles are deemed to meet the criteria pollutant exhaust emission standards of this part and you may state in the application for certification that your vehicles comply with all the requirements of this part related to criteria pollutant exhaust emission standards instead of submitting test data:

(i) Model year 2026 and earlier vehicles with installed engines certified to the standards specified in 40 CFR 86.007–11 or 86.008–10.

(ii) Model year 2027 and later vehicles with installed engines certified to the standards specified in 40 CFR part 1036.

(iii) Specialty vehicles with installed engines certified as specified in § 1037.605.

(iv) Glider kits and glider vehicles with installed engines certified as specified in § 1037.635.

(2) This part includes additional specific requirements for the following types of vehicles:

(i) New tractors that include auxiliary power units. See paragraph (c) of this section.

(ii) Vehicles subject to evaporative or refueling standards under § 1037.103.

(b) Heavy-duty vehicles with no installed propulsion engine, such as battery electric vehicles, are subject to criteria pollutant standards under this part. The emission standards that apply are the same as the standards that apply for compression-ignition engines under 40 CFR 86.007–11 or 1036.104 for a given model year.

(1) You may state in the application for certification that vehicles with no installed propulsion engine comply with all the requirements of this part related to criteria emission standards instead of submitting test data. Tailpipe emissions of criteria pollutants from vehicles with no installed propulsion engine are deemed to be zero.

(2) Vehicles with no installed propulsion engines may not generate NO_x credits.

(c) Starting in model year 2024, auxiliary power units installed on new tractors, including tractors that are

glider vehicles or tractors with no installed propulsion engine, must be certified to the PM emission standard specified in 40 CFR 1039.699. For model years 2021 through 2023, the APU engine must be certified under 40 CFR part 1039 with a deteriorated emission level for PM at or below 0.15 g/kW-hr. Selling, offering for sale, or introducing or delivering into commerce in the United States or importing into the United States a new tractor subject to this standard is a violation of 40 CFR 1068.101(a)(1) unless the auxiliary power unit has a valid certificate of conformity and the required label showing that it meets the PM standard specified in 40 CFR 1039.699 as described in this paragraph (c).

§§ 1037.105 and 1037.106 [Removed]

- 122. Remove §§ 1037.105 and 1037.106.

§ 1037.115 [Amended]

- 123. Amend § 1037.115 by removing paragraphs (e) and (f).

- 124. Amend § 1037.120 by revising paragraphs (a), (b), and (c) to read as follows:

§ 1037.120 Emission-related warranty requirements.

(a) *General requirements.* You must warrant to the ultimate purchaser and each subsequent purchaser that each new vehicle, including all parts of its emission control system, meets two conditions:

(1) It is designed, built, and equipped so it conforms at the time of sale to the ultimate purchaser with the requirements of this part.

(2) It is free from defects in materials and workmanship that cause the vehicle to fail to conform to the requirements of this part during the applicable warranty period.

(b) *Warranty period.* (1) Your emission-related warranty must be valid for at least:

(i) 5 years or 50,000 miles for heavy-duty vehicles at or below 19,500 pounds GVWR.

(ii) 5 years or 100,000 miles for heavy-duty vehicles above 19,500 pounds GVWR.

(2) You may offer an emission-related warranty more generous than we require. The emission-related warranty for the vehicle may not be shorter than any basic mechanical warranty you provide to that owner without charge for the vehicle. Similarly, the emission-related warranty for any component may not be shorter than any warranty you provide to that owner without charge for that component. This means that your warranty for a given vehicle

may not treat emission-related and nonemission-related defects differently for any component. The warranty period begins when the vehicle is placed into service.

(c) *Components covered.* The emission-related warranty covers fuel cell stacks, RESS, and other components used with battery electric vehicles and fuel cell electric vehicles. The emission-related warranty covers all components whose failure would increase a vehicle's evaporative and refueling emissions (for vehicles subject to evaporative and refueling emission standards). The emission-related warranty covers components that are part of your certified configuration even if another company produces the component.

* * * * *

- 125. Revise § 1037.125 to read as follows:

§ 1037.125 Maintenance instructions and allowable maintenance.

Give the ultimate purchaser of each new vehicle written instructions for properly maintaining and using the vehicle with respect to evaporative and refueling emission control system, as applicable.

- 126. Amend § 1037.135 by removing and reserving paragraphs (c)(6) and (7) and revising paragraph (e). The revision reads as follows:

§ 1037.135 Labeling.

* * * * *

(e) You may ask us to approve modified labeling requirements in this part 1037 if you show that it is necessary or appropriate. For example, if you certify both the engine and vehicle, you may ask for approval to comply with labeling requirements with a single emission control information label. We will approve your request if your alternate label is consistent with the requirements of this part.

§§ 1037.140 and 1037.150 [Removed]

- 127. Remove §§ 1037.140 and 1037.150.

- 128. Amend § 1037.201 by removing and reserving paragraph (g) and revising paragraph (i). The revision reads as follows:

§ 1037.201 General requirements for obtaining a certificate of conformity.

* * * * *

(i) Vehicles and installed engines must meet exhaust, evaporative, and refueling emission standards and certification requirements as described in §§ 1037.102 and 1037.103, as applicable. Include the information described in 40 CFR part 86, subpart S, or 40 CFR 1036.205 in your application

for certification in addition to what we specify in § 1037.205 so we can issue a single certificate of conformity for all the requirements that apply for your vehicle and the installed engine.

■ 129. Revise § 1037.205 to read as follows:

§ 1037.205 What must I include in my application?

This section specifies the information that must be in your application, unless we ask you to include less information under § 1037.201(c). We may require you to provide additional information to evaluate your application.

(a) List the fuel type on which your vehicles are designed to operate (for example, diesel fuel or gasoline).

(b) For vehicles with propulsion engines, name all the engine families associated with the vehicle family.

(c) For any new tractors with auxiliary power units, name all the engine families associated with those auxiliary power units.

(d) For any vehicle using RESS (such as hybrid vehicles, fuel cell electric vehicles and battery electric vehicles), describe in detail all components needed to charge the system, store energy, and transmit power to move the vehicle.

(e) For vehicles subject to evaporative and refueling emission standards, include the following information:

(1) Describe the vehicle family's specifications and other basic parameters of the vehicle's design and emission controls. Explain how the emission control system operates. As applicable, describe in detail all system components for controlling emissions, including all auxiliary emission control devices (AECDs) and all fuel-system components you will install on any production vehicle. Identify the part number of each component you describe. For this paragraph (e), treat as separate AECDs any devices that modulate or activate differently from each other.

(2) Where applicable, describe all adjustable operating parameters (see § 1037.115), including production tolerances. For any operating parameters that do not qualify as adjustable parameters, include a description supporting your conclusion (see 40 CFR 1068.50(c)). Include the following in your description of each adjustable parameter:

(i) The nominal or recommended setting.

(ii) The intended practically adjustable range.

(iii) The limits or stops used to establish adjustable ranges.

(iv) Information showing why the limits, stops, or other means of

inhibiting adjustment are effective in preventing adjustment of parameters on in-use engines to settings outside your intended practically adjustable ranges.

(3) Identify the vehicle family's useful life.

(4) Describe your engineering analysis to demonstrate compliance with standards as described in § 1037.103(c), or include the following testing information:

(i) Describe any vehicles or components you selected for testing and the reasons for selecting them.

(ii) Describe any test equipment and procedures that you used, including any special or alternate test procedures you used.

(iii) Describe how you operated any emission-data vehicle before testing, including the duty cycle and the number of vehicle operating miles used to stabilize emission-related performance. Explain why you selected the method of service accumulation. Describe any scheduled maintenance you did, and any practices or specifications that should apply for our testing.

(iv) List the specifications of any test fuel to show that it falls within the required ranges we specify in 40 CFR part 1065.

(v) Identify the emission standards or FELs to which you are certifying vehicles in the vehicle family.

(vi) Where applicable, identify the vehicle family's deterioration factors and describe how you developed them. Present any emission test data you used for this.

(vii) Where applicable, state that you operated your emission-data vehicles as described in the application (including the test procedures, test parameters, and test fuels) to show you meet the requirements of this part.

(f) Include any maintenance instructions and warranty statements you will give to the ultimate purchaser of each new vehicle (see §§ 1037.120 and 1037.125).

(g) Describe your emission control information label (see § 1037.135).

(h) Unconditionally certify that all the vehicles in the vehicle family comply with the requirements of this part, other referenced parts of the CFR, and the Clean Air Act.

(i) Include good-faith estimates of U.S.-directed production volumes. We may require you to describe the basis of your estimates.

(j) Include other applicable information, such as information specified in this part or 40 CFR part 1068 related to requests for exemptions.

(k) Name an agent for service located in the United States. Service on this

agent constitutes service on you or any of your officers or employees for any action by EPA or otherwise by the United States related to the requirements of this part.

■ 130. Amend § 1037.225 by revising paragraphs (a)(1) and (f) to read as follows:

§ 1037.225 Amending applications for certification.

* * * * *

(a) * * *

(1) Add any vehicle configurations to a vehicle family that are not already covered by your application. For example, if your application identifies three possible engine models, and you plan to produce vehicles using an additional engine model, then you must amend your application before producing vehicles with the fourth engine model.

* * * * *

(f) You may ask us to approve a change to your FEL in certain cases after the start of production. The changed FEL may not apply to vehicles you have already introduced into U.S. commerce, except as described in this paragraph (f). You may ask us to approve a change to your FEL in the following cases:

(1) You may ask to raise your FEL for your vehicle family at any time. In your request, you must show that you will still be able to meet the emission standards as specified in subparts B and H of this part. Use the appropriate FELs with corresponding production volumes to calculate emission credits for the model year, as described in subpart H of this part.

(2) Where testing applies, you may ask to lower the FEL for your vehicle family only if you have test data from production vehicles showing that emissions are below the proposed lower FEL. Otherwise, you may ask to lower your FEL for your vehicle family at any time. The lower FEL applies only to vehicles you produce after we approve the new FEL. Use the appropriate FELs with corresponding production volumes to calculate emission credits for the model year, as described in subpart H of this part.

(3) You may ask to add an FEL for your vehicle family at any time.

* * * * *

■ 131. Revise § 1037.230 to read as follows:

§ 1037.230 Vehicle families.

For purposes of certifying your vehicles, divide your product line into vehicle families as follows:

(a) All vehicles identified in § 1037.102(a)(1)(i) and (ii) for a given

model year may be in a single vehicle family, except as follows:

(1) New tractors with auxiliary power units need to be in a separate vehicle family.

(2) Divide vehicles subject to evaporative or refueling standards into vehicle families as described in 40 CFR 86.1821.

(b) All specialty vehicles identified in § 1037.102(a)(1)(iii) for a given model year may be in a single vehicle family.

(c) All glider kits and glider vehicles in § 1037.102(a)(1)(iv) for a given model year may be in a single vehicle family.

(d) All vehicles with no installed propulsion engine for a given model year may be in a single vehicle family, except that new tractors with auxiliary power units must be in a separate vehicle family.

§§ 1037.231 and 1036.232 [Removed]

■ 132. Remove §§ 1037.231 and 1037.232.

■ 133. Revise and republish § 1037.235 to read as follows:

§ 1037.235 Testing requirements for certification.

This section describes the emission testing you must perform to show compliance with respect to the standards in subpart B of this part, and to determine any input values.

(a) Select emission-data vehicles that represent production vehicles and components for the vehicle family. Where the test results will represent multiple vehicles or components with different emission performance, use good engineering judgment to select worst-case emission data vehicles or components.

(b) Test your emission-data vehicles (including emission-data components) using the procedures and equipment referenced in subpart B of this part. Measure emissions (or other parameters, as applicable) using the specified procedures.

(c) We may perform confirmatory testing by measuring emissions (or other parameters, as applicable) from any of your emission-data vehicles.

(1) We may decide to do the testing at your plant or any other facility. If we do this, you must deliver the vehicle or component to a test facility we designate. The vehicle or component you provide must be in a configuration that is suitable for testing. If we do the testing at your plant, you must schedule it as soon as possible and make available the instruments, personnel, and equipment we need (see paragraph (g) of this section for provisions that apply specifically for testing a tractor's aerodynamic performance).

(2) If we measure emissions (or other parameters, as applicable) from your vehicle or component, the results of that testing become the official emission results for the vehicle or component. Note that changing the official emission result does not necessarily require a change in the declared modeling input value. Unless we later invalidate these data, we may decide not to consider your data in determining if your vehicle family meets applicable requirements in this part.

(3) Before we test one of your vehicles or components, we may set its adjustable parameters to any point within the practically adjustable ranges, if applicable.

(4) Before we test one of your vehicles or components, we may calibrate it within normal production tolerances for anything we do not consider an adjustable parameter. For example, this would apply for a vehicle parameter that is subject to production variability because it is adjustable during production, but is not considered an adjustable parameter (as defined in § 1037.801) because it is permanently sealed. For parameters that relate to a level of performance that is itself subject to a specified range (such as maximum power output), we will generally perform any calibration under this paragraph (c)(4) in a way that keeps performance within the specified range. Note that this paragraph (c)(4) does not allow us to test your vehicles in a condition that would be unrepresentative of production vehicles.

(d) You may ask to use carryover data for a vehicle or component from a previous model year instead of doing new tests if the applicable emission-data vehicle from the previous model year remains the appropriate emission-data vehicle under paragraph (b) of this section.

(e) We may require you to test a second vehicle or component of the same configuration in addition to the vehicle or component tested under paragraph (a) of this section.

(f) If you use an alternate test procedure under 40 CFR 1065.10 and later testing shows that such testing does not produce results that are equivalent to the procedures referenced in subpart B of this part, we may reject data you generated using the alternate procedure.

§ 1037.241 [Removed]

■ 134. Remove § 1037.241.

■ 135. Amend § 1037.250 by revising paragraph (a) to read as follows:

§ 1037.250 Reporting and recordkeeping.

(a) By September 30 following the end of the model year, send the Designated Compliance Officer a report including the total U.S.-directed production volume of vehicles you produced in each vehicle family during the model year (based on information available at the time of the report) by engine family. Report uncertified vehicles sold to secondary vehicle manufacturers. We may waive the reporting requirements of this paragraph (a) for small manufacturers.

* * * * *

Subparts D through F [Reserved]

■ 136. Remove and reserve:

■ a. Subpart D, consisting of §§ 1037.301 through 1037.320;

■ b. Subpart E, consisting of § 1037.401; and

■ c. Subpart F, consisting of §§ 1037.501 through 1037.570.

■ 137. Amend § 1037.601 by revising paragraph (a)(1) to read as follows:

§ 1037.601 General compliance provisions.

(a) * * *

(1) Except as specifically allowed by this part or 40 CFR part 1068, it is a violation of 40 CFR 1068.101(a)(1) to introduce into U.S. commerce a vehicle containing an engine that is not certified to the applicable requirements of 40 CFR part 86 or 1036.

* * * * *

■ 138. Amend § 1037.605 by revising paragraph (d) to read as follows:

§ 1037.605 Installing engines certified to alternate standards for specialty vehicles.

* * * * *

(d) *Vehicle standards.* Vehicles qualifying under this section are subject to evaporative emission standards as specified in § 1037.103, but are exempt from the other requirements of this part, except as specified in this section and in § 1037.601. These vehicles must include a label as specified in § 1037.135.

§§ 1037.610 and 1037.615 [Removed]

■ 139. Remove §§ 1037.610 and 1037.615.

■ 140. Amend § 1037.620 by revising paragraph (c) introductory text to read as follows:

§ 1037.620 Responsibilities for multiple manufacturers.

* * * * *

(c) Component manufacturers providing test data to certifying vehicle manufacturers are responsible as follows for test components and emission test results provided to vehicle

manufacturers for the purpose of certification under this part:

* * * * *

■ 141. Amend § 1037.621 by revising paragraphs (b) and (d) introductory text and removing paragraph (g). The revisions read as follows:

§ 1037.621 Delegated assembly.

* * * * *

(b) You do not need an exemption to ship a vehicle that does not include installation or assembly of certain emission-related components if those components are shipped along with the vehicle. For example, you may generally ship fuel tanks along with vehicles rather than installing them on the vehicle before shipment. We may require you to describe how you plan to use this provision.

* * * * *

(d) Delegated-assembly provisions apply as specified in this paragraph (d) if the certifying vehicle manufacturer relies on a secondary vehicle manufacturer to procure and install auxiliary power units or natural gas fuel tanks. Apply the provisions of 40 CFR 1068.261, with the following exceptions and clarifications:

* * * * *

■ 142. Amend § 1037.622 by revising the introductory text and paragraph (a) and removing paragraph (d). The revisions read as follows:

§ 1037.622 Shipment of partially complete vehicles to secondary vehicle manufacturers.

This section specifies how manufacturers may introduce partially complete vehicles into U.S. commerce (or in the case of certain custom vehicles, introduce complete vehicles into U.S. commerce for modification by a small manufacturer). The provisions of this section are intended to accommodate normal business practices without compromising the effectiveness of certified emission controls. You may not use the provisions of this section to circumvent the intent of this part.

(a) The provisions of this section allow manufacturers to ship partially complete vehicles to secondary vehicle manufacturers or otherwise introduce them into U.S. commerce in the following circumstances:

(1) *Certified vehicles.* Manufacturers may introduce partially complete tractors into U.S. commerce if they are covered by certificates of conformity and are in certified configurations. See § 1037.621 for vehicles not yet in a certified configuration when introduced into U.S. commerce.

(2) *Uncertified vehicles that will be certified by secondary vehicle*

manufacturers. Manufacturers may introduce into U.S. commerce partially complete vehicles for which they do not hold the required certificate of conformity only as allowed by paragraph (b) of this section.

(3) *Exempted vehicles.* Manufacturers may introduce into U.S. commerce partially complete vehicles without a certificate of conformity if the vehicles are exempt under this part or under 40 CFR part 1068. This may involve the secondary vehicle manufacturer qualifying for the exemption.

* * * * *

§§ 1037.630 and 1037.631 [Removed]

■ 143. Remove §§ 1037.630 and 1037.631.

■ 144. Amend § 1037.635 by removing the introductory text and revising paragraphs (a) and (b). The revision reads as follows:

§ 1037.635 Glider kits and glider vehicles.

(a) Vehicles produced from glider kits and other glider vehicles are subject to the same standards as other new vehicles. For example, APUs installed on new glider tractors are subject to the certification requirement described in § 1037.102.

(b) Section 1037.601(a)(1) disallows the introduction into U.S. commerce of a new vehicle (including a vehicle assembled from a glider kit) unless it has an engine that is certified to the applicable standards in 40 CFR parts 86 and 1036. Except as specified otherwise in this part, the standards apply for engines used in glider vehicles as follows:

(1) [Reserved]

(2) The engine must meet the criteria pollutant standards of 40 CFR part 86 or 1036 that apply for the engine model year corresponding to the vehicle's date of manufacture.

(3) The engine may be from an earlier model year if the standards were identical to the currently applicable engine standards.

* * * * *

§§ 1037.640, 1037.645, 1037.655, 1037.660, 1037.665, and 1037.670 [Removed]

■ 145. Remove §§ 1037.640, 1037.645, 1037.655, 1037.660, 1037.665, and 1037.670.

Subpart H [Reserved]

■ 146. Remove and reserve subpart H, consisting of §§ 1037.701 through 1037.755.

■ 147. Revise and republish § 1037.801 to read as follows:

§ 1037.801 Definitions.

The following definitions apply to this part. The definitions apply to all subparts unless we note otherwise. All undefined terms have the meaning the Act gives to them. The definitions follow:

Act means the Clean Air Act, as amended, 42 U.S.C. 7401–7671q.

Adjustable parameter has the meaning given in 40 CFR 1068.30.

Adjusted Loaded Vehicle Weight means the numerical average of vehicle curb weight and GVWR.

Aftertreatment means relating to a catalytic converter, particulate filter, or any other system, component, or technology mounted downstream of the exhaust valve (or exhaust port) whose design function is to decrease emissions in the vehicle exhaust before it is exhausted to the environment. Exhaust gas recirculation (EGR) and turbochargers are not aftertreatment.

Aircraft means any vehicle capable of sustained air travel more than 100 feet off the ground.

Alcohol-fueled vehicle means a vehicle that is designed to run using an alcohol fuel. For purposes of this definition, alcohol fuels do not include fuels with a nominal alcohol content below 25 percent by volume.

Alternative fuel conversion has the meaning given for clean alternative fuel conversion in 40 CFR 85.502.

Amphibious vehicle means a motor vehicle that is also designed for operation on water. Note that high ground clearance that enables a vehicle to drive through water rather than floating on the water does not make a vehicle amphibious.

Auxiliary emission control device means any element of design that senses temperature, motive speed, engine speed (r/min), transmission gear, or any other parameter for the purpose of activating, modulating, delaying, or deactivating the operation of any part of the emission control system.

Auxiliary power unit means a device installed on a vehicle that uses an engine to provide power for purposes other than to (directly or indirectly) propel the vehicle.

Battery electric vehicle means a motor vehicle powered solely by an electric motor where energy for the motor is supplied by one or more batteries that receive power from an external source of electricity. Note that this definition does not include hybrid vehicles or plug-in hybrid electric vehicles.

Calibration means the set of specifications and tolerances specific to a particular design, version, or application of a component or assembly

capable of functionally describing its operation over its working range.

Carryover means relating to certification based on emission data generated from an earlier model year.

Certification means relating to the process of obtaining a certificate of conformity for a vehicle family that complies with the emission standards and requirements in this part.

Certified emission level means the highest deteriorated emission level in a vehicle family for a given pollutant from either transient or steady-state testing.

Class means relating to GVWR classes, as follows:

(1) *Class 2b* means relating to heavy-duty motor vehicles at or below 10,000 pounds GVWR.

(2) *Class 3* means relating to heavy-duty motor vehicles above 10,000 pounds GVWR but at or below 14,000 pounds GVWR.

(3) *Class 4* means relating to heavy-duty motor vehicles above 14,000 pounds GVWR but at or below 16,000 pounds GVWR.

(4) *Class 5* means relating to heavy-duty motor vehicles above 16,000 pounds GVWR but at or below 19,500 pounds GVWR.

(5) *Class 6* means relating to heavy-duty motor vehicles above 19,500 pounds GVWR but at or below 26,000 pounds GVWR.

(6) *Class 7* means relating to heavy-duty motor vehicles above 26,000 pounds GVWR but at or below 33,000 pounds GVWR.

(7) *Class 8* means relating to heavy-duty motor vehicles above 33,000 pounds GVWR.

Complete vehicle has the meaning given in the definition for *vehicle* in this section.

Compression-ignition has the meaning given in § 1037.101.

Date of manufacture means the date on which the certifying vehicle manufacturer completes its manufacturing operations, except as follows:

(1) Where the certificate holder is an engine manufacturer that does not manufacture the chassis, the date of manufacture of the vehicle is based on the date assembly of the vehicle is completed.

(2) We may approve an alternate date of manufacture based on the date on which the certifying (or primary) manufacturer completes assembly at the place of main assembly, consistent with the provisions of § 1037.601 and 49 CFR 567.4.

Designated Compliance Officer means one of the following:

(1) For compression-ignition engines, *Designated Compliance Officer* means

Director, Diesel Engine Compliance Center, U.S. Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; *complianceinfo@epa.gov*; *www.epa.gov/ve-certification*.

(2) For spark-ignition engines, *Designated Compliance Officer* means Director, Gasoline Engine Compliance Center, U.S. Environmental Protection Agency, 2000 Traverwood Drive, Ann Arbor, MI 48105; *complianceinfo@epa.gov*; *www.epa.gov/ve-certification*.

Deteriorated emission level means the emission level that results from applying the appropriate deterioration factor to the official emission result of the emission-data vehicle. Note that where no deterioration factor applies, references in this part to the *deteriorated emission level* mean the official emission result.

Deterioration factor means the relationship between the highest emissions during the useful life and emissions at the low-hour test point, expressed in one of the following ways:

(1) For multiplicative deterioration factors, the ratio of the highest emissions to emissions at the low-hour test point.

(2) For additive deterioration factors, the difference between the highest emissions and emissions at the low-hour test point.

Diesel exhaust fluid (DEF) means a liquid reducing agent (other than the engine fuel) used in conjunction with selective catalytic reduction to reduce NO_x emissions. *Diesel exhaust fluid* is generally understood to be an aqueous solution of urea conforming to the specifications of ISO 22241.

Dual-fuel means relating to a vehicle or engine designed for operation on two different fuels but not on a continuous mixture of those fuels. For purposes of this part, such a vehicle or engine remains a dual-fuel vehicle or engine even if it is designed for operation on three or more different fuels.

Electronic control module has the meaning given in 40 CFR 1065.1001.

Emission control system means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from a vehicle.

Emission-data component means a vehicle component that is tested for certification. This includes vehicle components tested to establish deterioration factors.

Emission-data vehicle means a vehicle (or vehicle component) that is tested for certification. This includes vehicles tested to establish deterioration factors.

Emission-related component has the meaning given in 40 CFR part 1068, appendix A.

Emission-related maintenance means maintenance that substantially affects emissions or is likely to substantially affect emission deterioration.

Excluded means relating to vehicles that are not subject to some or all of the requirements of this part as follows:

(1) A vehicle that has been determined not to be a “motor vehicle” is excluded from this part.

(2) Certain vehicles are excluded from the requirements of this part under § 1037.5.

(3) Specific regulatory provisions of this part may exclude a vehicle generally subject to this part from one or more specific standards or requirements of this part.

Exempted has the meaning given in 40 CFR 1068.30. Note that exempted vehicles are not considered to be excluded.

Extended idle means tractor idle operation during which the engine is operating to power accessories for a sleeper compartment or other passenger compartment. Although the vehicle is generally parked during extended idle, the term “parked idle” generally refers to something different than extended idle.

Family emission limit (FEL) means an emission level declared by the manufacturer to serve in place of an otherwise applicable emission standard under the ABT program in subpart H of this part. The *family emission limit* must be expressed to the same number of decimal places as the emission standard it replaces.

Flexible-fuel means relating to an engine designed for operation on any mixture of two or more different fuels.

Fuel cell electric vehicle means a motor vehicle powered solely by an electric motor where energy for the motor is supplied by hydrogen fuel cells. Fuel cell electric vehicles may include energy storage from the fuel cells or from regenerative braking in a battery.

Fuel system means all components involved in transporting, metering, and mixing the fuel from the fuel tank to the combustion chamber(s), including the fuel tank, fuel pump, fuel filters, fuel lines, carburetor or fuel-injection components, and all fuel-system vents. It also includes components for controlling evaporative emissions, such as fuel caps, purge valves, and carbon canisters.

Fuel type means a general category of fuels such as diesel fuel or natural gas. There can be multiple grades within a single fuel type, such as high-sulfur or low-sulfur diesel fuel.

Gaseous fuel means a fuel that has a boiling point below 20 °C.

Glider kit means either of the following:

(1) A new vehicle that is incomplete because it lacks an engine, transmission, and/or axle(s).

(2) Any other new equipment that is substantially similar to a complete motor vehicle and is intended to become a complete motor vehicle with a previously used engine (including a rebuilt or remanufactured engine). For example, incomplete heavy-duty tractor assemblies that are produced on the same assembly lines as complete tractors and that are made available to secondary vehicle manufacturers to complete assembly by installing used/remanufactured engines, transmissions and axles are glider kits.

Glider vehicle means a new motor vehicle produced from a glider kit, or otherwise produced as a new motor vehicle with a with a used/remanufactured engine.

Good engineering judgment has the meaning given in 40 CFR 1068.30. See 40 CFR 1068.5 for the administrative process we use to evaluate good engineering judgment.

Gross combination weight rating (GCWR) means the value specified by the vehicle manufacturer as the maximum weight of a loaded vehicle and trailer, consistent with good engineering judgment. For example, compliance with SAE J2807 is generally considered to be consistent with good engineering judgment, especially for Class 3 and smaller vehicles.

Gross vehicle weight rating (GVWR) means the value specified by the vehicle manufacturer as the maximum design loaded weight of a single vehicle, consistent with good engineering judgment.

Heavy-duty engine means any engine used for (or for which the engine manufacturer could reasonably expect to be used for) motive power in a heavy-duty vehicle.

Heavy-duty vehicle means any motor vehicle that has a GVWR above 8,500 pounds. An incomplete vehicle is also a heavy-duty vehicle if it has a curb weight above 6,000 pounds or a basic vehicle frontal area greater than 45 square feet.

Hybrid has the meaning given in 40 CFR 1036.801. Note that a hybrid vehicle is a vehicle with a hybrid engine or other hybrid powertrain. This includes plug-in hybrid electric vehicles.

Hydrocarbon (HC) means the hydrocarbon group on which the emission standards are based for each fuel type. For alcohol-fueled vehicles, HC means nonmethane hydrocarbon equivalent (NMHCE) for exhaust

emissions and total hydrocarbon equivalent (THCE) for evaporative emissions. For all other vehicles, HC means nonmethane hydrocarbon (NMHC) for exhaust emissions and total hydrocarbon (THC) for evaporative emissions.

Identification number means a unique specification (for example, a model number/serial number combination) that allows someone to distinguish a particular vehicle from other similar vehicles.

Incomplete vehicle has the meaning given in the definition of *vehicle* in this section.

Light-duty truck has the meaning given in 40 CFR 86.1803–01.

Light-duty vehicle has the meaning given in 40 CFR 86.1803–01.

Low-mileage means relating to a vehicle with stabilized emissions and represents the undeteriorated emission level. This would generally involve approximately 4000 miles of operation.

Manufacture means the physical and engineering process of designing, constructing, and/or assembling a vehicle.

Manufacturer has the meaning given in section 216(1) of the Act. In general, this term includes any person who manufactures or assembles a vehicle (including an incomplete vehicle) for sale in the United States or otherwise introduces a new motor vehicle into commerce in the United States. This includes importers who import vehicles for resale, entities that manufacture glider kits, and entities that assemble glider vehicles.

Medium-duty passenger vehicle (MDPV) has the meaning given in 40 CFR 86.1803.

Model year means one of the following for compliance with this part. Note that manufacturers may have other model year designations for the same vehicle for compliance with other requirements or for other purposes:

(1) For vehicles with a date of manufacture on or after January 1, 2021, *model year* means the manufacturer's annual new model production period based on the vehicle's date of manufacture, where the model year is the calendar year corresponding to the date of manufacture, except as follows:

(i) The vehicle's model year may be designated as the year before the calendar year corresponding to the date of manufacture if the engine's model year is also from an earlier year. You may ask us to extend your prior model year certificate to include such vehicles. Note that § 1037.601(a)(2) limits the extent to which vehicle manufacturers may install engines built in earlier calendar years.

(ii) The vehicle's model year may be designated as the year after the calendar year corresponding to the vehicle's date of manufacture. For example, a manufacturer may produce a new vehicle by installing the engine in December 2023 and designating it as a model year 2024 vehicle.

(2) For Phase 1 vehicles with a date of manufacture before January 1, 2021, *model year* means the manufacturer's annual new model production period, except as restricted under this definition and 40 CFR part 85, subpart X. It must include January 1 of the calendar year for which the model year is named, may not begin before January 2 of the previous calendar year, and it must end by December 31 of the named calendar year. The model year may be set to match the calendar year corresponding to the date of manufacture.

(i) The manufacturer who holds the certificate of conformity for the vehicle must assign the model year based on the date when its manufacturing operations are completed relative to its annual model year period. In unusual circumstances where completion of your assembly is delayed, we may allow you to assign a model year one year earlier, provided it does not affect which regulatory requirements will apply.

(ii) Unless a vehicle is being shipped to a secondary vehicle manufacturer that will hold the certificate of conformity, the model year must be assigned prior to introduction of the vehicle into U.S. commerce. The certifying manufacturer must redesignate the model year if it does not complete its manufacturing operations within the originally identified model year. A vehicle introduced into U.S. commerce without a model year is deemed to have a model year equal to the calendar year of its introduction into U.S. commerce unless the certifying manufacturer assigns a later date.

Motor vehicle has the meaning given in 40 CFR 85.1703.

New motor vehicle has the meaning given in the Act. It generally means a motor vehicle meeting the criteria of either paragraph (1) or (2) of this definition. *New motor vehicles* may be complete or incomplete.

(1) A motor vehicle for which the ultimate purchaser has never received the equitable or legal title is a *new motor vehicle*. This kind of vehicle might commonly be thought of as “brand new” although a *new motor vehicle* may include previously used parts. For example, vehicles commonly known as “glider kits,” “glider vehicles,” or “gliders” are new motor vehicles. Under this definition, the vehicle is new from

the time it is produced until the ultimate purchaser receives the title or places it into service, whichever comes first.

(2) An imported heavy-duty motor vehicle originally produced after the 1969 model year is a *new motor vehicle*.

Noncompliant vehicle means a vehicle that was originally covered by a certificate of conformity, but is not in the certified configuration or otherwise does not comply with the conditions of the certificate.

Nonconforming vehicle means a vehicle not covered by a certificate of conformity that would otherwise be subject to emission standards.

Nonmethane hydrocarbon (NMHC) means the sum of all hydrocarbon species except methane, as measured according to 40 CFR part 1065.

Nonmethane hydrocarbon equivalent (NMHCE) has the meaning given in 40 CFR 1065.1001.

Official emission result means the measured emission rate for an emission-data vehicle on a given duty cycle before the application of any required deterioration factor, but after the applicability of regeneration adjustment factors.

Owners manual means a document or collection of documents prepared by the vehicle manufacturer for the owners or operators to describe appropriate vehicle maintenance, applicable warranties, and any other information related to operating or keeping the vehicle. The owners manual is typically provided to the ultimate purchaser at the time of sale. The owners manual may be in paper or electronic format.

Oxides of nitrogen has the meaning given in 40 CFR 1065.1001.

Particulate trap means a filtering device that is designed to physically trap all particulate matter above a certain size.

Percent (%) has the meaning given in 40 CFR 1065.1001. Note that this means percentages identified in this part are assumed to be infinitely precise without regard to the number of significant figures. For example, one percent of 1,493 is 14.93.

Petroleum means gasoline or diesel fuel or other fuels normally derived from crude oil. This does not include methane or liquefied petroleum gas.

Placed into service means put into initial use for its intended purpose, excluding incidental use by the manufacturer or a dealer.

Plug-in hybrid electric vehicle means a hybrid vehicle that has the capability to charge one or more batteries from an external source of electricity while the vehicle is parked.

Preliminary approval means approval granted by an authorized EPA representative prior to submission of an application for certification, consistent with the provisions of § 1037.210.

Rechargeable Energy Storage System (RESS) has the meaning given in 40 CFR 1065.1001.

Relating to as used in this section means relating to something in a specific, direct manner. This expression is used in this section only to define terms as adjectives and not to broaden the meaning of the terms.

Revoke has the meaning given in 40 CFR 1068.30.

Round has the meaning given in 40 CFR 1065.1001.

Scheduled maintenance means adjusting, repairing, removing, disassembling, cleaning, or replacing components or systems periodically to keep a part or system from failing, malfunctioning, or wearing prematurely. It also may mean actions you expect are necessary to correct an overt indication of failure or malfunction for which periodic maintenance is not appropriate.

Secondary vehicle manufacturer anyone that produces a vehicle by modifying a complete vehicle or completing the assembly of a partially complete vehicle. For the purpose of this definition, “modifying” generally does not include making changes that do not remove a vehicle from its original certified configuration. However, custom sleeper modifications and alternative fuel conversions that change actual vehicle aerodynamics are considered to be modifications, even if they are permitted without recertification. This definition applies whether the production involves a complete or partially complete vehicle and whether the vehicle was previously certified to emission standards or not. Manufacturers controlled by the manufacturer of the base vehicle (or by an entity that also controls the manufacturer of the base vehicle) are not secondary vehicle manufacturers; rather, both entities are considered to be one manufacturer for purposes of this part.

Spark-ignition has the meaning given in § 1037.101.

Suspend has the meaning given in 40 CFR 1068.30.

Test sample means the collection of vehicles or components selected from the population of a vehicle family for emission testing. This may include testing for certification, production-line testing, or in-use testing.

Test vehicle means a vehicle in a test sample.

Test weight means the vehicle weight used or represented during testing.

Total hydrocarbon has the meaning given in 40 CFR 1065.1001. This generally means the combined mass of organic compounds measured by the specified procedure for measuring total hydrocarbon, expressed as a hydrocarbon with an atomic hydrogen-to-carbon ratio of 1.85:1.

Total hydrocarbon equivalent has the meaning given in 40 CFR 1065.1001. This generally means the sum of the carbon mass contributions of non-oxygenated hydrocarbon, alcohols and aldehydes, or other organic compounds that are measured separately as contained in a gas sample, expressed as exhaust hydrocarbon from petroleum-fueled vehicles. The atomic hydrogen-to-carbon ratio of the equivalent hydrocarbon is 1.85:1.

Tractor means a truck designed primarily for drawing other motor vehicles and not so constructed as to carry a load other than a part of the weight of the vehicle and the load so drawn. This includes most heavy-duty vehicles specifically designed for the primary purpose of pulling trailers, but does not include vehicles designed to carry other loads. For purposes of this definition “other loads” would not include loads carried in the cab, sleeper compartment, or toolboxes. Examples of vehicles that are similar to tractors but that are not *tractors* under this part include dromedary tractors, automobile haulers, straight trucks with trailers hitches, and tow trucks. *Ultimate purchaser* means, with respect to any new vehicle, the first person who in good faith purchases such new vehicle for purposes other than resale.

United States has the meaning given in 40 CFR 1068.30.

Upcoming model year means for a vehicle family the model year after the one currently in production.

U.S.-directed production volume means the number of vehicle units, subject to the requirements of this part, produced by a manufacturer for which the manufacturer has a reasonable assurance that sale was or will be made to ultimate purchasers in the United States.

Useful life means the period during which a vehicle is required to comply with all applicable emission standards.

Vehicle means equipment intended for use on highways that meets at least one of the criteria of paragraph (1) of this definition, as follows:

(1) The following equipment are vehicles:

(i) A piece of equipment that is intended for self-propelled use on highways becomes a vehicle when it

includes at least an engine, a transmission, and a frame. (*Note:* For purposes of this definition, any electrical, mechanical, and/or hydraulic devices attached to engines for the purpose of powering wheels are considered to be transmissions.)

(ii) A piece of equipment that is intended for self-propelled use on highways becomes a vehicle when it includes a passenger compartment attached to a frame with one or more axles.

(2) Vehicles may be complete or incomplete vehicles as follows:

(i) A *complete vehicle* is a functioning vehicle that has the primary load carrying device or container (or equivalent equipment) attached when it is first sold as a vehicle. Examples of equivalent equipment would include fifth wheel trailer hitches, firefighting equipment, and utility booms.

(ii) An *incomplete vehicle* is a vehicle that is not a complete vehicle.

Incomplete vehicles may also be cab-complete vehicles. This may include vehicles sold to secondary vehicle manufacturers.

(iii) You may ask us to allow you to certify a vehicle as incomplete if you manufacture the engines and sell the unassembled chassis components, as long as you do not produce and sell the body components necessary to complete the vehicle.

Vehicle configuration means a unique combination of vehicle hardware and calibration (related to measured or modeled emissions) within a vehicle family. Vehicles with hardware or software differences, but that have no hardware or software differences related to measured or modeled emissions may be included in the same vehicle configuration. Vehicles within a vehicle configuration differ only with respect to normal production variability or factors unrelated to measured or modeled emissions.

Vehicle family has the meaning given in § 1037.230.

Void has the meaning given in 40 CFR 1068.30.

Volatile liquid fuel means any fuel other than diesel or biodiesel that is a liquid at atmospheric pressure and has a Reid Vapor Pressure higher than 2.0 pounds per square inch.

We (us, our) means the Administrator of the Environmental Protection Agency and any authorized representatives.

■ 148. Amend § 1037.805 by removing “CO2DEF” and “CO2PTO” from table 4 to paragraph (d) and revise paragraph (e). The revision reads as follows:

§ 1037.805 Symbols, abbreviations, and acronyms.

* * * * *

(e) *Other acronyms and abbreviations.* This part uses the following additional abbreviations and acronyms:

TABLE 5 TO PARAGRAPH (e) OF § 1037.805—OTHER ACRONYMS AND ABBREVIATIONS

Acronym	Meaning
AECD	auxiliary emission control device.
AES	automatic engine shutdown.
APU	auxiliary power unit.
CD	charge-depleting.
CFR	Code of Federal Regulations.
CITT	curb idle transmission torque.
CS	charge-sustaining.
DOT	Department of Transportation.
EPA	Environmental Protection Agency.
FEL	Family Emission Limit.
GAWR	gross axle weight rating.
GCWR	gross combination weight rating.
GVWR	gross vehicle weight rating.
HVAC	heating, ventilating, and air conditioning.
ISO	International Organization for Standardization.
NARA	National Archives and Records Administration.
NHTSA	National Highway Traffic Safety Administration.
RESS	rechargeable energy storage system.
SAE	SAE International.
SEE	standard error of the estimate.
SKU	stock-keeping unit.
U.S.C.	United States Code.

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§ 1037.810 [Removed]

■ 149. Remove § 1037.810.

§ 1037.825 [Amended]

■ 150. Amend § 1037.825 by removing and reserving paragraph (e)(1)(i) and removing paragraph (e)(1)(iv).

Appendices A Through E to Part 1037 [Removed]

■ 151. Remove appendices A through E to part 1037.

PART 1039—CONTROL OF EMISSIONS FROM NEW AND IN-USE NONROAD COMPRESSION-IGNITION ENGINES

■ 152. The authority citation for part 1039 continues to read as follows:

Authority: 42 U.S.C. 7401–7671q.

■ 153. Amend § 1039.699 by revising paragraphs (a) and (n) to read as follows:

§ 1039.699 Emission standards and certification requirements for auxiliary power units for highway tractors.

(a) This section describes emission standards and certification requirements

for auxiliary power units (APU) installed on highway tractors subject to standards under 40 CFR 1037.102 starting in model year 2024.

* * * * *

(n) If a highway tractor manufacturer violates 40 CFR 1037.102 by installing an APU from you that is not properly certified and labeled, you are presumed to have caused the violation (see 40 CFR 1068.101(c)).

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