PETITION
OF YOUTH AND YOUNG ADULT PETITIONERS
AND SISTERS OF MERCY ECOLOGY, MERCY ECOLOGY INC.,
AND NATURE’S TRUST RHODE ISLAND
TO THE RHODE ISLAND
DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

To undertake an emergency rulemaking action, to initiate a formal rulemaking process using Petitioners’ draft as a proposed rule, and to complete in a timely fashion a final rule to ensure that Rhode Island does its fair share to reduce greenhouse gas emissions, and to reduce existing atmospheric concentrations of such gasses, based on the best available science in order to protect the health of Petitioners, other groups at special health risk, and the Public Trust

For an electronic version of this Petition follow this link:
http://naturestrustri.org/legal-action/
Notice of action on this petition or other matters should be addressed to:

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Kingston, RI 02881
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NaturesTrustRI@pobox.com
Pursuant to RI Gen L § 42-35, and 250-RICR-20-00-1 youth and young adults including Neelam Ahmed, Carmen Boyan, Alexandra Duryea, Stephen Follett, Victoria and Jeremi Huertas, Meghan Janicki, Eve Kelley, Chloe Moers, Catherine Scott, Greg (Chip) Slaybaugh, Philip Tierney and Nature’s Trust Rhode Island Sisters of Mercy Ecology,¹ and Mercy Ecology, Inc.²—collectively “Petitioners”—hereby petition the Rhode Island Department of Environmental Management (DEM) for adoption of the proposed rule set forth in section 1.2 of this Petition.

DEM should act upon this request based upon the statutory and regulatory authorities set forth in section 1.1.3 of this Petition, and pursuant to its obligations under the RI Const. Art. I, § 17,³ and the Public Trust Doctrine.

For the reasons set forth in sections 1.1.1 and 1.1.2 of this Petition, prompt action is necessary to protect the rights and common welfare of present and future generations of Rhode Islanders by implementing an enforceable, effective greenhouse gas reduction strategy that is based on the best available science and to ensure that Rhode Island does its share to restore the concentration of greenhouse gases in the atmosphere to safe levels. Moreover, the consequent rule is necessary to ensure that the worst impacts of climate change and ocean acidification are avoided and do not cause further, catastrophic and irreversible harm to present and future generations of Rhode Islanders.

This Petition includes distinct and severable elements, as set forth in sections 1.2.3 through 1.2.12. Petitioners expect the Rhode Island Department of Environmental Management to treat them severably, and to explain its denials, if any, on an element by element basis. Petitioners request that any comments with respect to the Department’s consideration or determination on this Petition be reduced to writing and placed in the rulemaking record.

This Petition incorporates by reference the climate-damages Complaint brought on July 2, 2018 by the Rhode Island Attorney General against a number of companies,⁴ and the related statements by Rhode Island officials.⁵ The filing of the Complaint by the Attorney General is clear evidence of the State’s full awareness that climate change is a grave problem for the Petitioners as well as all others in Rhode Island.

The State’s Complaint contains a review of some harms suffered by Rhode Islanders as a result of climate change. The attachments to this Petition also contain such a review, which is more extensive and reflective of the best available science than the Complaint prepared by the State. Moreover, our science review focuses in particular on harm suffered by Petitioners.

Dedicated to the memory of late Nature’s Trust Rhode Island board of director members Tom Nerney, 1942–2018, and Robert Malin, 1953–2018

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¹Nature’s Trust Rhode Island and Sisters of Mercy Ecology are 501(c)(3) non-profit corporations
²Mercy Ecology Inc.— http://mercyecology.org/
³See page 4, item (c).
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1 PROPOSED RULE

Typography

**Small-capitalized** phrases refer to terms defined in the Glossary beginning on page 11 of this Petition. For those reading this Petition as a PDF file on a computer these terms are live links.

1.1 Preamble

Human activity, primarily in the form of burning fossil fuels, has increased the global concentration of **greenhouse gasses** in the atmosphere. Science informs us that the increase in atmospheric carbon dioxide (CO$_2$) concentrations has already contributed significantly to warming the global climate system and has acidified the oceans, causing serious adverse effects to human health, safety, welfare and natural systems of the earth.

In many cases, these developments are accelerating and have outpaced projections of how quickly increased atmospheric carbon dioxide concentrations will impact our climate, and how quickly we might reach *tipping points* that would make it impossible to return to safe climate conditions.$^6$

The increased presence in the atmosphere of other **greenhouse gasses**, such as methane in particular, which has been seriously underestimated by the federal Environmental Protection Agency, is adding to this risk.$^7$ Accordingly, urgent action is now required to reduce all greenhouse gas emissions, and pull out of the atmosphere gases that exceed safe levels.

Although the Rhode Island government has recognized the threat, it has failed to act in a manner proportionate to the need documented by the **best available science**. The failure again this year of the Rhode Island legislature to act on proposals to address these facts, combined with the retreat of the Trump cabinet from even mentioning the words “climate change,” means that Petitioners now face an imminent peril to their health, safety, and welfare, requiring emergency action.

Left unabated, global climate destabilization and ocean acidification will have long-term, catastrophic effects on human systems and the habitability of Rhode Island, the nation, and the world as a whole.

As this Petition points out,$^8$ young people are significantly more at risk than the general population from health hazards of climate change. The younger generation will be exposed to more severe risks for a much longer time than today’s decision makers. Other particularly vulnerable populations are at higher risk because of the failure to apply the principles of **environmental justice**. Accordingly, consistent with health practices in general, the proposed rule would require the application of the **Precautionary Principle**.

1.1.1 Prompt action is essential

According to the **best available science**, it is essential to act urgently to protect the climate system upon which life on earth depends.$^9$

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$^6$See section A.11, page 138. Also see the keywords *tipping point*, *surprises*, and *outpacing projections* in the index starting on page 193.

$^7$See item number 2 on page 128; also see section A.9.2, page 123 and keywords *EPA methane underestimates* and *fugitive methane* in the index starting on page 193.

$^8$See section A.2.5.2 on page 39 and keyword *children’s health* in the index starting on page 193.

$^9$See abstract of J. E. Hansen *et al.*, “Assessing ‘dangerous climate change’: required reduction of carbon emissions to protect young people, future generations and nature.” In: *PLOS One* (2013). doi:
(a) by reducing the global concentration of CO\textsubscript{2} in the atmosphere rapidly to less than 350 parts per million\textsuperscript{10} from current levels of 410 parts per million;\textsuperscript{11} that is\textsuperscript{12}

(b) by ensuring that cumulative global emissions of CO\textsubscript{2} do not exceed a global emissions budget of 500 GtC; and by pursuing policies to restore 100 GtC into the biosphere, including the soil; and

(c) by accounting for non-CO\textsubscript{2} greenhouse gases, as set forth in items (a) and (b) in section 1.1.2.\textsuperscript{13}

The Petitioners are already at imminent peril of adverse effects to their health, effects that will continue to multiply as climate change continues, as the State has now admitted in its liability Complaint. Accordingly, Petitioners seek an emergency rule under RI Gen L § 42-35-2.10, as well as the commencement of action on a final rule. The fact that the State has not to date acted in a manner proportionate to this health risk does not bar it from doing so at this time and invoking its duly authorized emergency authority.

The rules proposed herein, in sections 1.2.2 through 1.2.12, are based on the best available science. If the Rhode Island Department of Environmental Management does not agree with what Petitioners consider as such or with the required emission reductions, Petitioners respectfully ask that it present:

(d) the climate science it relies on; and

(e) the Rhode Island emission reductions it considers sufficient to avert any threat to the climate and to Petitioners' future health and well-being.

1.1.2 Timeframe of emission reductions

(a) The emissions reductions outlined in section 1.1.1 must all be accomplished on a timescale commensurate with the one implied by compelling observations in recent years showing that global warming is destabilizing the Arctic, Antarctic, and the Gulf Stream system faster than anticipated.\textsuperscript{14} These effects in turn are driving the acceleration of the disruption of the global climate system. **The pertinent timescale is decadal.**


\textsuperscript{12}While it may seem confusing, items (a) and (b) are equivalent as illustrated by this quote (J. E. Hansen and P. Kharecha, Assessing ‘dangerous climate change’: required reduction of carbon emissions to protect young people, future generations and nature. 2013. url: http://www.columbia.edu/~jeh1/mailings/2013/20131202_PopularSciencePlosOneE.pdf (visited on July 8, 2018)): We conclude that human-made warming could be held to about 1°C (1.8°F) if cumulative industrial-era fossil fuel emissions are limited to 500 GtC (gigatons of carbon, where a gigaton is one billion metric tons) and if policies are pursued to restore 100 GtC into the biosphere, including the soil. This scenario leads to reduction of atmospheric CO\textsubscript{2} to 350 ppm by 2100, as needed to restore Earth’s energy balance and approximately stabilize climate.

\textsuperscript{13}Also see the discussion in this Petition on page 26, which is based on Hansen et al., “Target Atmospheric CO\textsubscript{2}: Where Should Humanity Aim?” supra note 10.

\textsuperscript{14}The requirements set forth in items (a) and (b) of section 1.1.1 must be implemented on a decadal timescale or faster. This is of particular relevance for the impact of methane as far as the State of Rhode Island is concerned, as much of the energy consumed is generated by combustion of natural gas. This process

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Indeed, a recent study states that what will happen in the next one of two decades will determine whether the earth’s climate trajectory will be one leading to “Hothouse Earth,” *i.e.*, run-away climate change beyond human control.\(^{15}\)

(b) These emission reductions are consistent with developments during the last decade, when greenhouse gas emissions have come increasingly from the production, transportation and burning of natural gas, leading to increased emissions of uncombusted methane, aka fugitive methane.

Petitioners note that in the recent complaint for damages filed by the Rhode Island Attorney General,\(^{16}\) as well as introductory statements by other officials,\(^{17}\) the State clearly identifies natural gas as responsible in part for the harm to the State and its Public Trust.

Numerous recent studies clearly demonstrate that fugitive methane emissions are consistently much higher than Environmental Protection Agency estimates.\(^{18}\) In addition to the fact that these emissions have been underestimated, the measurements of emissions of fugitive, unburned \(\text{CH}_4\) (*e.g.* smokestack and facility-scale emissions\(^{19}\)) do not capture the amount of carbon dioxide that results from those greenhouse gases that break down over time after their emission. Consistent with the time-scale of the observed developments in the Arctic and Antarctic,\(^{20}\) the proposed rule provides a formula that properly reflects the potency of methane as a greenhouse gas, which vastly exceeds that of carbon dioxide. The formula also accounts for the atmospheric chemistry of methane and its impact on the greenhouse gas content of the atmosphere.

Rhode Island’s current approach to reducing emissions is not based on the *BEST AVAILABLE SCIENCE*. Moreover, the State does not currently take into account *EMBODIED EMISSIONS* in products consumed in Rhode Island but emitted during manufacturing or transportation outside the state.

Proposing a rule just for a single state, *viz.* Rhode Island, should arguably be based on how much of the problem it has created. However, to avoid the many complex questions this approach would create, the proposed rule would fix Rhode Island’s *SHARE* of this global responsibility simply as the State’s percentage of the current world population. The proposed rule would require that consumption-based emissions be counted in the same manner as in-boundary emissions for the purposes of measuring the State’s responsibilities.


Specifically see the summaries of the 2016 and 2017 Arctic Report Cards in sections A.6.21.1 and A.6.21.2 on pages 90 and 91. Also see the observations about the ice melt doubling times by Hansen *et al.* summarized on page 101. Additional evidence can also be found by means of the index starting on page 193; see keywords *polar amplification*, *Atlantic Meridional Overturning Circulation*, *surprises*, and *outpacing projections*.

\(^{16}\)Supra note 4.

\(^{17}\)Supra note 5.

\(^{18}\)The keywords *EPA methane underestimates* and *fugitive methane* in the index starting on page 193 provide page numbers in this Petition where many of these studies are reviewed.

\(^{19}\)See the discussion on page 129

\(^{20}\)Also see sections A.6.27 and A.7 on pages 108 and 109 and the keyword *surprises* in the index starting on page 193.
1.1.3 Purpose of proposed rule

The purpose of this proposed rule is to protect the rights of present and future generations of Rhode Islanders to a healthy atmosphere and a stable climate system, \(^{21}\) and to safeguard the heritage of the State of Rhode Island. Specifically, this rule is intended to:

(a) Fulfill the State of Rhode Island’s fiduciary duty to prevent waste and substantial impairment of Public Trust resources;

(b) The guarantee the individual constitutional rights that: \(^{22}\)

The people shall continue to enjoy and freely exercise all the rights of fishery, and the privileges of the shore, to which they have been heretofore entitled under the charter and usages of this state, including but not limited to fishing from the shore, the gathering of seaweed, leaving the shore to swim in the sea and passage along the shore; and they shall be secure in their rights to the use and enjoyment of the natural resources of the state with due regard for the preservation of their values . . . .

(c) Fulfill the State of Rhode Island’s constitutional duty: \(^{23}\)

...to provide for the conservation of the air, land, water, ... providing adequate resource planning for the control and regulation of the use of the natural resources of the state and for the preservation, regeneration and restoration of the natural environment of the state.

(d) Fulfill the State of Rhode Island’s constitutional duties regarding equal protection and due process of the laws that: \(^{24}\)

All laws ... should be made for the good of the whole; and the burdens of the state ought to be fairly distributed among its citizens. No person shall be deprived of life, liberty or property without due process of law, nor shall any person be denied protection of the laws. No otherwise qualified person shall, solely by reason of race, gender or handicap be subject to discrimination by the state, its agents or any person or entity doing business with the state . . . .

(e) Fulfill the Rhode Island Department of Environmental Management’s statutory duty: \(^{25}\)


\(^{22}\) RI Const. Art. I, § 17. The text of this constitutional requirement has been divided here between items (b) and (c) in the text to emphasize that its scope covers both the well-established impacts of climate change on the offshore environment as well as those on the air and land. It is the position of Petitioners that the entire text of the paragraph is part of the State’s Public Trust Doctrine, and hence that the duties involved are all of a fiduciary character. The science presented in this Petition is clear that climate change triggers both clauses of § 17. Moreover, Petitioners note the liability complaint filed by the Attorney General (supra note 4) concedes that climate change has damaged the Public Trust, and hence triggers the obligations of the Rhode Island government under the Constitution.

\(^{23}\) RI Const. Art. I, § 17.

\(^{24}\) RI Const. Art. I, § 2.

\(^{25}\) RI Gen L § 42-17.1-2(1).
to supervise and control the protection, development, planning, and utilization of the natural resources of the state, such resources, including, but not limited to: water, plants, trees, soil, clay, sand, gravel, rocks and other minerals, air, mammals, birds, reptiles, amphibians, fish, shellfish, and other forms of aquatic, insect, and animal life; . . . .

(f) Fulfill the statutory duty of Rhode Island Department of Environmental Management:

[to establish minimum standards for the establishment and maintenance of salutary environmental conditions, including standards and methods for the assessment and the consideration of the cumulative effects on the environment of regulatory actions and decisions, which standards for consideration of cumulative effects shall provide for: (i) Evaluation of potential cumulative effects that could adversely effect public health and/or impair ecological functioning; . . . .

(g) Fulfill Rhode Island Department of Environmental Management’s statutory duties of the Resilient Rhode Island Act of 2014, with respect to the climate of the State of Rhode Island:

Powers and duties of state agencies—Exercise of existing authority
Consideration of the impacts of climate change shall be deemed to be within the powers and duties of all state departments, agencies, commissions, councils, and instrumentalities, including quasi-public agencies, and each shall be deemed to have and to exercise among its purposes in the exercise of its existing authority, the purposes set forth in this chapter pertaining to climate change mitigation, adaption, and resilience in so far as climate change affects the mission, duties, responsibilities, projects, or programs of the entity.

(h) Act pursuant to the goals set forth in RI Gen L § 10-20-1, concerning environmental rights:

The general assembly finds and declares that each person is entitled by right to the protection, preservation, and enhancement of air, water, land, and other natural resources located within the state . . . . The legislature further declares its policy to create and maintain within the state conditions under which man and nature can exist in productive harmony in order that present and future generations may enjoy clear air and water, productive land, and other natural resources with which this state has been endowed.

Petitioners note this list of duties and obligations is not intended as a full articulation of other Rhode Island Department of Environmental Management duties and obligations that may be applicable.

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26 RI Gen L § 42-17.1-2(14).
27 RI Gen L § 42-6.2.
28 RI Gen L § 42-6.2-8.
1.2 Emission reductions

1.2.1 Emergency and final rules

(a) Petitioners request that the Rhode Island Department of Environmental Management, pursuant to the authorities and duties set forth in the Preamble, issue an emergency rule, pursuant to RI Gen L § 42-35-2.10 requiring that any agency action [as defined by RI Gen L § 42-35-1(2)] shall adhere to the requirements set forth in sections 1.2.3, 1.2.4, and 1.2.5 of this Petition.

(b) Petitioners further request that the Rhode Island Department of Environmental Management, pursuant to the authorities and duties set forth in the preamble, propose and issue a final rule pursuant to RI Gen L § 42-35 requiring that any agency action shall adhere to the requirements set forth in sections 1.2.2 through 1.2.12 of this Petition. The Department shall complete the final rule so it goes into effect immediately upon expiration of the emergency rule established pursuant to paragraph 1.2.1(a) of this section.

1.2.2 Greenhouse gas emission reduction

For the year beginning on January 1, 2019, and for every calendar year thereafter, emissions shall be reduced according to one of the following pathways: 29

(a) 6% during the first year and by the same absolute amount each subsequent year (LINEAR reduction);

(b) 13% during the first year and by the same fraction of the previous year each subsequent year (EXPONENTIAL reduction);

29 As discussed in item (b) in section 1.1.2, given the increased role of methane in the global energy production, and danger posed by tipping points—see note 6—greenhouse gas emissions besides those of CO2 have to be accounted for correctly. This must be done by measuring GREENHOUSE GAS emissions in GtCe, the unit of CARBON DIOXIDE EQUIVALENT emissions.

In reference to items (a) and (b) in section 1.1.1, it should be noted that the numbers in Tab. 1 are based on Hansen et al., “Assessing ‘dangerous climate change’: required reduction of carbon emissions to protect young people, future generations and nature,” supra note 9. In contradistinction to the latter reference, the rules set forth in this Petition use the aggregate of all GREENHOUSE GASES expressed in units of GtCe.

Table 1: Start year and required CO2 emission reduction for LINEAR (L) and EXPONENTIAL pathways (E).

<table>
<thead>
<tr>
<th>year</th>
<th>L (%)</th>
<th>E (%)</th>
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<tbody>
<tr>
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<td>3</td>
<td>5</td>
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<tr>
<td>2012</td>
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<td>6</td>
<td>13</td>
</tr>
<tr>
<td>2020</td>
<td>7</td>
<td>15</td>
</tr>
</tbody>
</table>
1.2.3 Best available science

With respect to any decisions that may impact emissions, require that all State of Rhode Island agencies shall act in accordance with the best available science.\(^30\)

1.2.4 Precautionary Principle

With respect to any decisions that may impact emissions, all State of Rhode Island agencies shall act in accordance with the Precautionary Principle.

1.2.5 Environmental justice

With respect to any decisions that may impact emissions, require that all State of Rhode Island agencies shall act in accordance with the principles of environmental justice.

1.2.6 Emissions budget

The State of Rhode Island shall not exceed its share of the global emissions budget of 500 GtCe.\(^31\)

1.2.7 Rhode Island emissions accounting

(a) To ensure accurate accounting of the State of Rhode Island’s GHG emissions, the State shall create in-boundary emissions inventories and consumption-based emissions inventories for greenhouse gases. For purposes of the emissions inventories, greenhouse gases shall be expressed in terms of their instantaneous carbon dioxide equivalent emissions. These emissions inventories shall be used to account for Rhode Island’s yearly expenditure from its share of the greenhouse gas emissions budget and for a full life cycle assessment of Rhode Island emissions by including embodied emissions. The emissions inventories shall initially be established so as to be the same as those currently used in Oregon with two important distinctions:\(^33\)

\(^{30}\)As exhaustively documented in chapter A regarding Rhode Island, the Northeast, the U.S., and the earth as a whole.

\(^{31}\)See Hansen et al., “Assessing ‘dangerous climate change’: required reduction of carbon emissions to protect young people, future generations and nature,” supra note 9. Also see section A.10.1, page 134 in particular.

\(^{32}\)See Consumption-based Greenhouse Gas Emissions Inventory for Oregon. Oregon Department of Environmental Quality. URL: http://www.oregon.gov/deq/mm/Pages/Consumption-based-GHG.aspx (visited on Apr. 12, 2018), and references therein.

\(^{33}\)The term “inventory” may be confusing as it tends to obscure that emissions inventories are tools designed to keep track of how much is spent from the emission budget. The federal Environmental Protection Agency uses the term emissions “inventory” in the context of greenhouse gas emissions as a list of sources and sinks of emissions. Power plants, trucks, and furnaces are the obvious examples of sources. Because of their uptake and storage of carbon dioxide, forests, vegetation, and soils act as sinks. The term emissions “inventory” is typically used to specify the amount of greenhouse gas sources and sinks that make up the emissions inventory emit or absorb.

Another complication is that methane decays in the atmosphere (with a half-life of about 9 years) and produces carbon dioxide in the process. In other words, as time progresses, methane decays and is a source of carbon dioxide. The implication is that, as far as spending down the emission budget is concerned,
(a)(1) **Carbon dioxide equivalent** emissions in units of **GtCe** shall be based on the **instantaneous global warming potential** as specified by Intergovernmental Panel on Climate Change (IPCC)’s *Fifth Assessment Report*. The required **GWP** shall be updated according to future Intergovernmental Panel on Climate Change (IPCC) assessments and be kept up to date with the **best available science**.

(a)(2) **Emissions** from electric power generated in Rhode Island shall be included in the **in-boundary emissions inventories**. Exceptions may be made for documented instances of exports of Rhode Island power to recipients, foreign or domestic, that use greenhouse gas accounting systems equivalent to the one proposed here.

(b) The cumulative **greenhouse gas emissions** of the State of Rhode Island will be the running sum of the **in-boundary emissions inventories** and the **consumption-based emissions inventories**, where individual terms in the running sum are weighted by the instantaneous global warming potential (**GWP**₀) and shall account for the atmospheric chemistry, as detailed in the Technical Appendix, chapter B, page 150. **Emissions** shall be accumulated on the basis of the yearly emission of **greenhouse gasses** and will start, when this rule is promulgated, with the State of Rhode Island’s **share** of the **cumulative global emissions**.

Rhode Island Department of Environmental Management shall carefully examine available data sets that can be used to calculate **greenhouse gas emissions** for purposes of this rule, pick the one that currently provides the best combination of accuracy and timeliness, publish its analysis and decision, and review this determination annually.

(c) The running sum of cumulative Rhode Island’s emissions, as set forth in paragraph (b) of this section, shall account for atmospheric chemical processes affecting **greenhouse gasses** and shall employ the lifetimes of non-carbon dioxide gasses as specified by the Intergovernmental Panel on Climate Change (IPCC).

1.2.8 **Carbon storage in the biosphere**

The State of Rhode Island shall also do its **share** of storing 100 **GtC** of CO₂ in the biosphere, including the soil, for example by means of reforestation, improved agricultural, and forestry this decay of methane appears both on the debit side as an expenditure and in subsequent years on the credit side having partially decayed, while the debit side shows the decay product, carbon dioxide, as an expenditure. This dynamic can be only captured within the ubiquitous **GWP** approach when one employs the **instantaneous global warming potential** (**GWP**₀) for each gas. See the Technical Appendix in section B for further details. (M. P. Nightingale, “Proposed policymaker-friendly metric of radiative effects of greenhouse gases.” In: *Preprint* [2018]. URL: [http://phys.uri.edu/nigh/gwp-preprint.pdf](http://phys.uri.edu/nigh/gwp-preprint.pdf) [visited on Sept. 17, 2018])


36 Table 8.7 of Stocker et al., *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, supra note 34, p. 714, contains the required life times of greenhouse gases. Also see supra note 33 for the issues entailed by the oxidation in the atmosphere of CH₄ in particular.
practices. The State of Rhode Island may satisfy its obligation in this regard by arranging for such storage outside the State of Rhode Island boundaries, provided Rhode Island’s storage is clearly defined, maintained and monitored, at least annually, and any lost storage capacity is replaced promptly.

1.2.9 Negative emissions

The State of Rhode Island shall make a plan to deal with any NEGATIVE EMISSIONS that may become required should the State of Rhode Island fail to otherwise stay within its SHARE of the GLOBAL EMISSIONS BUDGET or carbon storage requirement, as set forth in section 1.2.8. These negative emissions shall offset other EMISSIONS in the State of Rhode Island’s accounting system and budget share, even if such negative emissions are generated outside the State of Rhode Island’s boundaries on its behalf.

For the purpose of calculating required negative emissions, the State shall use this estimate: on a global basis, 1 part per million atmospheric CO$_2$ is the approximate equivalent of 2.12 GtC or any estimate updated in accordance with the BEST AVAILABLE SCIENCE.

1.2.10 Climate action plan

(a) Within six months of publication of the final regulations, the Rhode Island Department of Environmental Management, with input from citizens and other stakeholders, including organizations familiar with climate change and climate fairness issues, shall adopt a Climate Action Plan to meet the requirements specified herein.

(b) Within six months of the issuance of the Climate Action Plan, the Rhode Island Department of Environmental Management shall propose interim benchmarks for EMISSION and NEGATIVE EMISSIONS, for each year by various sectors of the economy, or for emitter size or such characteristics as the Department may determine.

(c) Adhering to the radiative forcings listed in Figure TS.7 of T. F. Stocker et al., “Technical Summary.” In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Ed. by T. F. Stocker et al. 2013. url: https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_TS_FINAL.pdf, p. 57 and future updates thereof, the Climate Action Plan shall make a proposal for regulating, in accordance with their instantaneous global warming potential and atmospheric decay times as specified by the most up to date Intergovernmental Panel on Climate Change (IPCC) assessment, greenhouse gases other than carbon dioxide and methane mentioned in sections 1.2.3 through 1.2.6.

1.2.11 Revisions

The Rhode Island Department of Environmental Management, with input from citizens and other stakeholders, shall amend the Climate Action Plan as necessary to address any adjustments to the requirements and interim benchmarks affected by revisions to these regulations within six months of such revisions.


38See caption of Figure 9 of Id., p. 587.
Two years after the publication of the final regulations, and every five years thereafter until Rhode Island has phased out all EMISSIONS, the Rhode Island Department of Environmental Management shall amend the final regulations to adjust the emission reduction requirements and interim benchmarks as necessary to ensure that the State of Rhode Island is reducing its EMISSIONS in a manner consistent with the requirements of the regulations set forth in sections 1.2.2 through 1.2.10.

1.2.12 Recommendations to the Rhode Island Legislature

Promptly after the adoption of the final regulations, the Rhode Island Department of Environmental Management shall recommend to the Legislature amendments to any pertinent statutes such as for any authority that would clarify or facilitate the authority of Rhode Island Department of Environmental Management to establish or enforce the EMISSIONS reductions and biosphere storage requirements, interim benchmarks, carbon accounting and emissions inventory requirements set forth in this Petition and the Climate Action Plan.
2 GLOSSARY

agency means any State department, agency, commission, council, and instrumentality, including any quasi-public agency.

best available science means:

1. the most current scientific knowledge and understanding of qualified scientists on safe levels of atmospheric CO$_2$ and other GREENHOUSE GASSES and their near- and long-term impacts;

2. the most current scientific knowledge and understanding from qualified scientists as to the GREENHOUSE GAS emission reductions and CO$_2$ sequestration required to stabilize the climate system and preserve a habitable and safe climate system for future generations; and

3. In cases in which current scientific knowledge does not suffice, the PRECAUTIONARY PRINCIPLE must be applied.

carbon dioxide equivalent (CO$_2$e) means referring to one or more greenhouse gases in terms of unit that expresses the amount of CO$_2$ that would have the same effect on the climate system of the earth. See GtCe for the unit of measurement associated with this concept.

consumption-based emissions inventory means a GREENHOUSE GAS emissions inventory focused on all emissions associated with materials and services, including electricity and fuels, consumed in Rhode Island, including estimates of embodied emissions associated with the life cycle of such materials and services. These emissions are included regardless of whether they physically originate in Rhode Island. A consumption-based emissions inventory uniquely counts out-of-state emissions associated with producing and transporting the products, services, and fuels consumed in Rhode Island, including fuels used to generate electricity in Rhode Island.

cumulative global emissions means, when applied to carbon dioxide emissions, the sum total of global emissions since the Industrial Revolution. In the long run, on the time scale of centuries, this quantity determines the global warming temperature increase. Section A.10.1, page 134, contains a detailed explanation. In the case of other greenhouse gases, such as in particular methane, and relevant on the time scale of decades and for avoiding tipping points—see section A.7, page 109—the atmospheric chemistry of oxidation must be taken into account in determination of this sum, as defined in the Technical Appendix, section B, page 150.

39 As specifically set forth in the requirements of section 1.2.7, and further on page 7, this emissions inventory is based upon that used in Oregon but with two explicit differences. See Oregon Greenhouse Gas Sector-Based Inventory Data. Oregon Department of Environmental Quality. URL: http://www.oregon.gov/deq/aq/programs/Pages/GHG-Inventory.aspx (visited on Jan. 15, 2018).

40 The consumption-based emissions inventory supplements the in-boundary emissions inventory by estimating the emissions—both in-state and elsewhere—associated with consumption by Rhode Island residents, businesses and governments. More than half of these consumption-based emissions occur in other states or nations and are not included in the in-boundary emissions inventory. Together these inventories tell a more complete story of how Rhode Island contributes to climate change and, by extension, opportunities to reduce emissions. This is based on supra note 32.
decisions that may impact emissions refers to any agency action that could add to the State’s inventory of \textit{greenhouse gas} emissions, pursuant to section 1.2.6 (page 7) of the proposed rule, including decisions concerning grants, contracts for purchase of goods or services, permits, and any comments on proposed legislation.

embodied emissions means emissions associated with producing and transporting the products, services, and fuels (including fuels used to generate electricity) that are produced out of state but consumed in Rhode Island.

emission means GHG emissions both in-boundary and consumption based.

environmental justice means the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. In this context, “fair treatment” means no group of people should bear a disproportionate share of the negative environmental consequences resulting from industrial, governmental and commercial operations or policies.

exponential means up to a constant forming a geometric progression, \textit{i.e.} a sequence of quantities in which up to a constant subsequent quantities have a constant ratio. For example after subtracting 1, the ratio of subsequent numbers in the sequence 2, 4, 10, 28, 81, \ldots is 3.

GHG (acronym) \textit{greenhouse gas}

gigaton means the Standard International unit of mass equal to a $10^{15}$ gram = Pg = peta-gram.

global emissions budget means the global, cumulative amount of greenhouse gas that accumulated as of the Industrial Revolution can be emitted into the atmosphere without running the unacceptable risk of making life on earth as we know it becomes impossible. For further details see section A.10, page 133. The expression given in note 211 can be used to estimate how much of the CO$_2$ global emitted budget has been spent at a given time and how much of the budget will remain in the future.

global warming potential means the metric used to gauge the global warming impact of a mass of greenhouse gas relative to the same mass of CO$_2$. This quantity is undefined unless \textit{time horizon} is explicitly specified or unambiguously implied.


Trade has multiple implications for GHG emissions. First, increased demand for transportation of goods and people generates emissions. For example, freight transport now represents more than a third of the total energy use in the transportation sector .....Secondly, trade allows countries to partially “de-link” consumption from emissions, since some goods and services are produced abroad, with opposite implications for the importing and exporting countries.

\footnote{See the definitions contained in the review of the briefing before the U. S. Commission on Civil Rights and the Environmental Protection Agency starting on page 50.}


**greenhouse gas** means any gas that contributes to anthropogenic global warming. This includes carbon dioxide (CO$_2$), methane (CH$_4$), nitrous oxide (N$_2$O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF$_6$), and nitrogen trifluoride (NF$_3$).\(^ {43}\)

GtC means **gigaton** of carbon, the equivalent of \( \frac{3}{11} \text{GtCO}_2 \approx 0.27 \text{GtCO}_2 \).

GtCe means **gigaton of carbon dioxide equivalent**, a unit of mass used to quantify the amount of one or more greenhouse gases. The quantity is obtained by multiplying each gas by its **global warming potential** and, in the case of more than one gas, by summing over the gasses.\(^ {44}\) The result is an estimate of the amount of carbon dioxide that would have the same global warming impact as this (these) greenhouse gas(es). This quantity was designed as a tool to assist policy makers. It has its limitations and is undefined unless a **time horizon** is explicitly specified or unambiguously implied. Also see **carbon dioxide equivalent**.\(^ {45}\)

GtCO$_2$ means **gigaton of carbon dioxide**: \( \frac{11}{3} \text{GtC} \approx 3.7 \text{GtC} \).

**GWP** (acronym) **global warming potential**

**GWP$_0$** means the **instantaneous global warming potential** of a greenhouse gas.

**in-boundary emissions inventory** means the greenhouse gas emissions inventory focused on all emissions produced within the State and includes emissions associated with the extraction, transportation, refinement, and combustion of fossil fuels extracted in Rhode Island, whether such transportation, refinement, or combustion occurs within or outside of the state. In-boundary emissions inventories exclude many of the emissions associated with materials and goods produced outside, and imported into the State.\(^ {46}\)

**instantaneous global warming potential** means the global warming potential with

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\(^ {44}\) Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act December 7, 2009 Final. Climate Change Division, Office of Atmospheric Programs U.S. Environmental Protection Agency. URL: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100DDS.PDF?Dockey=P100DDS.PDF (visited on Aug. 15, 2018), note 2 on p. ES-1.


\(^ {46}\) See note 39 on page 11.
life cycle assessment means, as Carnegie Mellon University defines it in its primer on this topic:

Life cycle assessment (LCA) is a way to investigate, estimate, and evaluate the environmental burdens caused by a material, product, process, or service throughout its life span. Environmental burdens include the materials and energy resources required to create the product, as well as the wastes and emissions generated during the process.

linear means forming an arithmetic progression, i.e. a sequence of quantities in which up to a constant subsequent quantities have a constant difference. For example the difference of subsequent numbers in the sequence 1, 4, 7, 10, 13, … is 3.

negative emissions means biological or technological methods the objective of which is the large-scale removal of carbon dioxide from the atmosphere. Such technological methods have not been tested to scale; for details see section 4, page 18.

Precautionary Principle refers to a public policy principle employed when a proposed activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically. In this context the proponent of an activity, rather than the public, should bear the burden of proof. The process of applying the Precautionary Principle must be open, informed and democratic and must include potentially affected parties. When the best available evidence indicates a range of risks, to base action on the worst-case scenario in the range rather than another alternative within that range.
share means a fraction of a global total, the fraction being the Rhode Island population divided by the global population at the time the proposed legislation is published.

small-capitalized phrases identify entries in this glossary.

time horizon means the time period used to calculate the average of the global warming impact of a greenhouse gas relative to that of CO₂. For substances that decay in the atmosphere, such as methane, the choice of the time horizon greatly influences the numerical value of the GLOBAL WARMING POTENTIAL. The vanishing time horizon provides exceptional status to INSTANTANEOUS GLOBAL WARMING POTENTIAL—see note 47 on page 14. This is in contrast with the choice of the 100-year time horizon used by the Environmental Protection Agency,⁵³ which is based on a value judgment lacking a scientific basis.⁵⁴
Climate change in Rhode Island currently poses a very real, extensively documented threat to the existence of Petitioners and their progeny, as well as to the res of the state itself.

Climate change is now scientifically well-established. The phenomena of change in the planet’s recent history, confirmed by means of the state-of-the-art technology, has no credible, alternative explanation.

Here, Petitioners present an up-to-date summary of the data supporting these conclusions. This includes information on threat assessments at the global and national level, for the Northeast region, and for Rhode Island in particular. This summary is drawn from a complete scientific review presented in chapter A, page 25.

1. **Key Point:** Climate change in our era has been caused by the extensive use of fossil fuels, which—when produced, transported, and consumed—release gases that alter our atmosphere. This slows down the rate at which the earth radiates back into space energy absorbed by daily exposure to the sun. Moreover, much of the main greenhouse gas, carbon dioxide, will “affect the climate system for many millennia” leading to a long-term increase of the planet’s average temperature, unless, as discussed below in Key Point 4 on page 18, we might be able to use “negative emissions” to remove the CO$_2$.

This causes the mean global temperature to increase, but it also increases the magnitude of the excursions about the mean. Because of this, 1,000-year weather extremes are becoming the new normal. (Also see page 61.) All of this contributes to the climate change we experience. Among these changes are temperatures higher than at any point in human history, escalating precipitation, storm intensity, sea level rise, and ocean acidification impacting the State of Rhode Island at an ever increasing rate.

Because of their heating effects one calls these emissions *greenhouse gases*. They come from fossil fuel use. We discuss other natural and anthropogenic emissions below in Key Point 9, page 20. As set forth in section A.3, page 51, for more than eight decades, scientific research has documented the increasing effects of greenhouse gases. Every United States president since Lyndon B. Johnson in 1965, and federal and state governments have known not only that science predicts climate change, but also that it has in fact been observed, as Hansen explained in groundbreaking testimony before a U.S. Senate committee in 1988. We now know that in many cases the rate of change

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has outpaced scientific predictions. Moreover, adverse changes in the climate can amplify themselves, a process known as positive feedback—see, e.g., polar amplification and tipping points in the index starting on page 193. Indeed, many in the scientific community expect climate change to accelerate so quickly that soon we will have a planet that is alien to the needs of many plant and animal life forms we know. We are now well into a war for the survival of our property, our progeny, and our fellow human beings on today’s front-lines of climate change.

2. **Key Point:** Since the beginning Industrial Revolution in 1750, human activity in the form of fossil fuel combustion has added greenhouse gases to the atmosphere at a rate that has been doubling every three to four decades. This exponential growth has added greenhouse gases to the pre-industrial atmosphere at a rate of 2–2.5% per year. The climate system has responded similarly, resulting in an existential threat to many life forms on earth in general and to human existence in particular. For further details see section A.3 on page 51. In particular, see Figs. 9 and 8.

Compared to older generations, our youth and generations to come are more at risk. We know that conditions will worsen over the course of their lifetimes. Moreover, they are at increased risk during their youth—see section A.2.5.2 on page 39.

A vast literature exists about the detailed progress of climate change, the changes it has caused already, and those projected to take place under a variety of scenarios. Temperatures in the sea, land and air, sea level rise, melting of sea-based ice shelves and land-based ice sheets have followed a similar pattern of change of the driving force, namely the exponential growth of the greenhouse gas contents of the atmosphere. This is confirmed by the findings of “[t]housands of studies conducted by tens of thousands of scientists around the world.” (See section A.1, page 25.)

3. **Key Point:** Major reviews of climate science agree on a number of more specific points. In section A.6, page 63, we highlight the key points from the Third National Climate Assessment and from Volume I of fourth installment in this series, which mainly focuses on the U.S., was released in mid-2017, and is required every four years by federal law; Volume II will be released at the end of 2018. Notwithstanding potential bias due to an administration that openly scorns the global scientific consensus and is susceptible to corporate influence—see page 145 and more generally section A.11.3, page 144—the latest national assessment includes such salient points as:

3.(a) Climate changes are fast and unambiguous; see section A.6.5.1, page 67;
3.(b) Climate change is human-caused; see section A.6.5.3, page 67;
3.(c) Without drastic cuts in emissions temperature could increase by 9°F (5°C); see section A.6.5.4, page 68;
3.(d) Because of their large thermal inertia, the oceans have a response time of several decades. Combined with the much longer residence time in the atmosphere of CO₂, as mentioned in Key Point 1, future warming is “baked in;” see section A.6.9.1, page 73;
3.(e) Sea level rise will disproportionately affect the coast of the United States Northeast; see section A.6.22.3 on page 99;

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3.(f) Increased depth and frequency of tidal floods will occur in Atlantic and Gulf cities; see section A.6.22.4;

3.(g) There will be an increase in frequency and extent of extreme flooding associated with coastal storms and “nor’easters;” see section A.6.22.5, page 99;

3.(h) Ocean acidification rate is unparalleled in at least 66 millions year; see section A.6.24.3;

3.(i) Substantial global greenhouse gas emission reductions are required before 2040; and zero or negative emissions subsequently; see section A.6.26.2, page 107;

3.(j) Tipping points, points of irreversible, and in some cases run-away changes to the climate system, are known to exist. Such instabilities are “notoriously difficult to foresee;” see sections A.6.27.1, page 108 and A.7, page 109.

A recent study—see page 109 argues that the next one or two decades will be crucial in determining whether the earth’s climate trajectory will lead to “Hothouse Earth,” i.e., tipping point beyond human control;

3.(k) Computer modeling is an invaluable tool for climate change prediction, and models tend to agree on the overall picture, but modeling in particular of the changes in the polar regions systematically underestimates the risk of irreversible changes; see section A.6.27.3, page 108. For instances in which observations outpace projections see section A.11, page 138.

4. Key Point: We do not yet have proven methods for permanently reducing the concentration of greenhouse gases in the atmosphere on a planetary scale. Among the methods under consideration, improved agricultural practices and ecosystem restoration are particularly promising. Removal of greenhouse gases from the atmosphere is also referred to as negative emissions. Without the development of such scrubbing technology, the future is grim. A major reason for this is that, as a result of delay and neglect in acknowledging and reducing greenhouse gases, further changes are already “baked in.” In other words, because of the thermal inertia of the oceans,

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64The vast majority of the citations in this chapter are to the “best climate science,” but we did not adhere strictly to this standard. Plain-language summaries about “scrubbing technology” are in infra notes 65, 66, and 67.


3 CLIMATE SCIENCE SUMMARY

mentioned in Key Point 3.(d), problems will continue to get worse even if we were to eliminate all greenhouse gas emissions right now. The same would still be true for some time if we start on a path of negative emissions.

During the decades it takes the oceans to adjust to the increased greenhouse gas contents of the atmosphere, the climate system will not fully show the effects of greenhouse gases emitted globally thus far. But, although we may not sense it on a day to day basis, during that time, the global average temperature will keep increasing, as will the increase in frequency of extreme weather events caused by climate change.

Nevertheless, the evidence is also clear that if we reduce greenhouse gas emissions sharply right away, present and future generations will have a much better chance of survival than if we let matters proceed unchecked. The less greenhouse gas we have in the atmosphere, the slower the planet will heat, the more time we will have possibly to develop the technology needed to scrub the atmosphere, and the more quickly that technology can have a real impact when deployed.

5. Key Point: Research of Hansen and coworkers occurs in peer-reviewed, scientific papers cited throughout this chapter.\(^{68}\) The emphasis on Hansen et al.’s work is based on our extensive review of the recent scientific literature. Our conclusion, first of all, is that this work is among the best available science on climate change. Secondly, this extensive body of work is consistent with the precautionary principle, as we discuss in more detail later on in section A.12, page A.12. Thirdly, we mention that the same scientific material has been the basis of legal review and commentary in other courts considering similar questions about the responsibilities of governments with respect to climate change.\(^{69,70}\)

6. Key Point: Climate change in Rhode Island currently poses a very real, carefully and extensively documented threat to the existence of Petitioners and their progeny, as well as to the rest of the State. Extensive materials identified in the Appendix, section A, page 25, on the Northeast region, and on Rhode Island in particular, make this abundantly clear. It should be noted that much of this information is known to and often produced by the Rhode Island Administration; see e.g. section A.2, page 30.

7. Key Point: As an integral part of the discussion of scientific evidence Petitioners point out that the current projections are very likely under-estimates of the real risks. In part this is due to scientists’ tendency to “err on the side of least drama,”\(^{71}\) as discussed in detail in sections A.11.1 and A.11, page 138 and 138.

Many scientists focus on their own specialties and, as a consequence, the full picture of the ever-accelerating, exponential rate of greenhouse gas emissions that started

\(^{68}\)See the index, page 193 under Hansen


\(^{70}\)For example, in the Juliana case, where the essence of the scientific basis discussed in this chapter can be found. See Declaration by Dr. James E. Hansen, UNITED STATES DISTRICT COURT DISTRICT OF OREGON EUGENE DIVISION, Case 6:15-cv-01517-TC, Document 47, filed 01/08/16 Page 1 of 11. URL: https://static1.squarespace.com/static/571d109b04426270152f5f5b9b1972c9e/146557211775/HansenSuppDecSupportingYouth.pdf (visited on Dec. 31, 2017).

during the Industrial Revolution may not always be apparent within the scope of their research. This leads to frequently under-estimated projections. We cover this topic in section A.11, page 138.

8. **Key Point:** An additional source of systematic underestimates of the impact of greenhouse gases is that both scientists and decision makers often fail to take natural gas emissions into account in a way that adequately reflects what we know about their consequences. We note here that natural gas consists predominantly of methane (CH$_4$), which is a very powerful greenhouse gas. Methane fuels more than 95% of the net electricity generation in Rhode Island.\(^{72}\)

Methane that escapes during production, transportation and utilization is known as fugitive methane; it is an inseparable part of its full life cycle. As to Rhode Island, this underrating of the impacts of natural gas is particularly acute because of:

- **8.(a)** An inadequate system to account for both greenhouse gases emitted in Rhode Island and embodied in the goods or energy consumed in Rhode Island—see (a) EMBODIED EMISSIONS; (b) page 29; and (c) section A.10 on page 136;
- **8.(b)** Systematic efforts by the State to add more natural gas infrastructure, notwithstanding knowledge of the serious consequences of doing so.\(^{73}\) The underlying scientific problems of methane in particular are discussed in section A.9, page 122.

9. **Key Point:** We note that there are other important sources of methane unrelated to energy production.\(^{74}\) They are of both anthropogenic and natural origin. These sources are particularly important for climate change and should be fully accounted for.

Among the methane sources of global importance unrelated to energy production are ruminant meat production,\(^{75}\) rice agriculture,\(^{76}\) landfills, and wastewater treatment.\(^{77}\) Natural sources of methane are microorganisms, wetlands, melting permafrost, and methane hydrates.\(^{78}\) The latter, which are found in copious amount in the Arctic, may be responsible for one of the possible “surprises” discussed in section A.7, page 109.


\(^{73}\)A particularly jarring example is Rhode Island Governor Gina Raimondo’s intention to move “ahead with cost-effective, regional energy infrastructure projects including expansion of natural gas capacity …..”(Raimondo to Meet with New England Governors April 23 to Discuss Regional Energy Infrastructure Challenges. Rhode Island Office of the Governor. 2015. URL: http://www.ri.gov/press/view/24624 [visited on Dec. 2, 2017]).


10. **Key Point:** Climate change also has national security implications. Pertaining to the Arctic, for example, we mention a response by Secretary of the Navy Richard Spencer on the Arctic, on April 19, 2018: “The damn thing melted.” This was a pithy reply, before the U.S. Senate Armed Services Committee, to the question what had prompted the recent revision of an Arctic strategy document written in 2014. For more on matters of national security see section A.8, page 116; recent developments in the Arctic are in sections A.6.21.1 and A.6.21.2, pages 90 and 91.

Effects of climate change that impact national security can significantly impact Rhode Island’s economy. A substantial portion of this economic activity involves military and military contractor facilities along the coast that may need to be relocated due to sea level rise, and not necessarily relocated to Rhode Island.

Experts predict that these matters of national security will greatly compound the already serious impacts of climate change—see section A.8, page 116.

11. **Key Point:** There is a great deal of scientific support for the concept of a **GLOBAL EMISSIONS BUDGET**, which refers to the estimated amount of greenhouse gas emissions the world can emit before the climate system spins out of control. The corresponding science is discussed in section A.10 and forms the basis of the relief requested.

12. **Key Point:** The science of climate change makes it clear that we are likely going to encounter sudden shifts for the worse, and that these could well come sooner rather than later. This is the reason why the proposed rule would adopt the **PRECAUTIONARY PRINCIPLE**. The Precautionary Principle is Principle 15 of the 1992 Rio Declaration to which the United States is bound. The principle is often compared to the “first do no harm” of the medical profession, and it is widely used when considering which public policy path to take when presented with options of potentially dangerous impact. The precautionary principle is discussed in section A.12, page 146.

13. **Key Point:** Decisions taken today may determine whether the earth’s climate system will follow a pathway leading to “Hothouse Earth,” a trajectory punctuated by a domino-like cascade of tipping points, the effect of which could include abrupt, changes of the biosphere, impossible for human societies to absorb and reverse. Indeed, as Rintoul et al. put it: Choices made in the next decade will determine what trajectory is realized.” Further details are discussed in section A.7, page 109.

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81Antarctica-2018.
1. Why is this citizen petition necessary?

Rhode Island’s climate is already changing for the worse, and the State has already acknowledged that this is due to greenhouse gas emissions. The science is clear: the situation is going to get much worse and quickly. Federal action is not forthcoming, so each state needs to act alone. The General Assembly has declined to step up to meet this urgent need. The expert agency created to deal with environmental problems, the Department of Environmental Management (DEM) must therefore act under its constitutional and statutory responsibilities to urgently to fill this breach. A Citizen Petition is being filed because DEM has not done so.

The Petition seeks both emergency action and the initiation of a public process to establish a permanent rule. Both are authorized by long-standing Rhode Island law. The Petition, if granted, would require the proposed rule be used as the initial basis of consideration because it covers a comprehensive set of issues that need to be addressed.

2. How is the Petition organized?

The Petition itself is comprised of only 25 pages, in addition to these Questions and Answers. The Proposed Rule itself is only a few pages, with ten provisions, some only a sentence long, and a glossary defining key terms. The document also includes several thoroughly documented appendices to assist DEM.

3. What are the key requirements of the Proposed Rule?

This proposal would establish a science-based set of requirements to deal with Rhode Island’s share of what must be accomplished to bring atmospheric concentrations of carbon dioxide down to levels that are safe for Petitioners. (For the reasons discussed below in Q and A 6, Rhode Island’s “share” is to be established based on its fraction of the total world population.)

(a) All State decisions that may impact greenhouse gas emissions are to be made in accordance with
   i. the best available science;
   ii. the Public Trust Doctrine;
   iii. the Precautionary Principle; and
   iv. principles of environmental justice

(b) Greenhouse gas emissions must be reduced every year in accordance with one of two pathways (in Tab. 1, page 6).

(c) The State shall not exceed its share of the global greenhouse gas emissions “budget” that has been established by the best available science, unless it can reduce atmospheric concentrations of greenhouse gases (negative emissions) by the amount of any excess.

(d) In calculating its emissions, the State is to include
   i. emissions from out-of-state necessary to produce and transport goods and services used in this State (based on a model already used in Oregon); and
   ii. emissions of greenhouse gases other than carbon dioxide, and in particular methane, are to be counted in accordance with an established formula that equates their impact on the environment to that of carbon dioxide.
(e) The State is to contribute its share to a biosphere storage (e.g., ecosystem restoration and soil improvement) that must be established and maintained according to the best available science.

(f) How does the Proposed Rule apply to individuals who use fossil fuels to heat or cool their homes, or businesses of different types and sizes?

Those requirements are not specified in the Proposed Rule. Rather, as set forth in proposed sections 1.2.10 and 1.2.11, these requirements will be decided, after input from citizens and other stakeholders, by establishing benchmarks in a Climate Action Plan to be developed soon after the regulations go into effect. That Plan is to be updated regularly. The General Assembly can, of course, step in at any time.

4. Does the DEM have the authority to issue such regulations?

Petitioners assert that it does, under the Rhode Island Constitution and various statutes. A short list is included in section 1.1.3 of this Petition. Section 1.2.12 of the Proposed Rule requires DEM to recommend to the General Assembly any authority that would help them establish or enforce the emission reductions, biosphere storage requirements, and other aspects of the Proposed Rule. Administrative agencies like DEM are established in the Executive branch of government, and given their powers, because there are some subjects that Legislators find too complex to tackle in detail or in a timely manner. The agencies are expected to use those authorities to the extent they exist. Of course the General Assembly can deny funding, or kill any Proposed or Final Rule, but they ought to have the benefit of a DEM proposal to consider.

5. The yearly reductions in greenhouse gas emissions that the Proposed Rule would require seem rather drastic. Are they really necessary? And what impact will compliance have on the Rhode Island economy?

These reductions are absolutely necessary according to the best available science. The reductions could have been less drastic had Rhode Island started down this pathway even five years ago, but that did not happen. Worse, the State failed to appreciate the impact of methane (natural gas) emissions, and its efforts over the last few years to add more, unnecessary natural gas has distracted attention from the real problem. If we wait longer, the required reductions will have to be steeper still, with an attendant stress on the economy. Whatever the doubts of the past about the availability and cost of renewable energy, they have been fully resolved and so we do have cost-effective alternatives to fossil fuels.

Granting this Petition will put into immediate effect the three key principles that should govern any agency action with regard to climate change: (1) use the best available science; (2) application of the Precautionary Principle; (3) and adherence to the principles of environmental justice. Granting this Petition would also initiate a process known as “proposed rulemaking.” The process involved, established by law, will ensure that impacts and alternatives will be evaluated, and the public fully involved in those discussions. The DEM must then, by law, base any action on the record of those proceedings. That decision is in turn subject to court review.

Often, one question asked in evaluating potential impact is whether other nearby States are taking similar action—i.e., whether it makes living and doing business in Rhode Island more expensive than in other nearby states. The entire world is going to have to do its share to ensure that we do not lose the one planet we know to be habitable; and
as there are no signs a federal approach is imminent for the United States, each State needs to act soon. Those who seize the good economic times to make this investment will be better off than their neighbors, and offer a much more long-term security to businesses and individuals alike.

6. Why does the proposal establish Rhode Island’s share of the world’s problem based on its share of world population?

It would really be much more fair to every State or country’s contribution to be based on their historical contribution to the problem. That is not likely to be to Rhode Island’s benefit, since we were an early contributor to the Industrial Revolution and greenhouse gas emissions ever since. But more significantly, Petitioners believe that it will be very difficult to agree on historical contributions, e.g., due to incomplete data. Rather than delaying action for years to study this problem, the proposal defines Rhode Island’s share of its obligations by percentage of world population.

7. Will establishing the Proposed Rule be the last word on this?

Probably not by itself. But right now, all Rhode Island has in place is set of very inadequate goals. A rule, however, will provide, a clear and more forceful sense of direction to individuals and businesses who are making investment decisions in their properties, as well as in their decisions about where to live and play. We have already seen how limited investments in renewable resources have paid off in green jobs and reductions in fossil fuel demands, but the federal tax credits for wind and solar could well be supplemented by state credits—and for converting from fossil fuel heating to sun, water and wind powered electrical appliances as well. An equitable, refundable tax on fossil fuels and stronger building code requirements are among important, possible actions.
A SCIENTIFIC BACKGROUND—DETAILS

A.1 Climate change essentials

The 2017 *Fourth National Climate Assessment*, of which we discuss the background and findings at length in section A.6, page 63, contains the following summary:82

The world has warmed over the last 150 years, especially over the last six decades, and that warming has triggered many other changes to Earth’s climate. Evidence for a changing climate abounds, from the top of the atmosphere to the depths of the oceans. Thousands of studies conducted by tens of thousands of scientists around the world have documented changes in surface, atmospheric, and oceanic temperatures; melting glaciers; disappearing snow cover; shrinking sea ice; rising sea level; and an increase in atmospheric water vapor. Rainfall patterns and storms are changing and the occurrence of droughts is shifting.

Although inequality in Rhode Island may be small on a global scale, the state will exemplify the following statement, contained in the prestigious medical journal The Lancet:83

**Climate change effects on health will exacerbate inequities between rich and poor**

Climate change will have its greatest effect on those who have the least access to the world’s resources and who have contributed least to its cause. Without mitigation and adaptation, it will increase health inequity especially through negative effects on the social determinants of health in the poorest communities.

Human activity—see page 65—primarily in the form of burning of fossil fuels, has increased the global atmospheric concentration of greenhouse gases.84 The details are complex, but the cause is straightforward: the exponential increase in greenhouse gases put into the atmosphere since the Industrial Revolution is forcing climate change exponentially, as basic mathematical physics implies, until saturation is reached. Note that we use the term *exponential* in the scientific sense, which corresponds to compound interest in finance. We refer to section A.3, page 51 for further details.

Indeed sophisticated scientific modeling and detailed observations have established beyond reasonable doubt that the increase in atmospheric concentrations mainly of carbon dioxide (CO$_2$), methane (CH$_4$), and nitrous oxide (N$_2$O) have caused global warming and acidified the oceans with significant adverse effects on human health, safety, welfare, and on life on earth in general. Left unabated, global climate destabilization, ocean acidification, and sea level rise will have long-term, catastrophic effects on the habitability of Rhode Island—see section A.2, page 30—the nation, and the globe.

As will be discussed in detail below, paleoclimatic studies have made it abundantly clear that the global average concentration of CO$_2$ in the atmosphere must be reduced to less

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than 350 parts per million to protect the climate system upon which humans and many other species depend. As Hansen and coworkers put it in 2008:\(^{85}\)

If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO\(_2\) will need to be reduced from its current 385 ppm [parts per million] to at most 350 ppm, but likely less than that. The largest uncertainty in the target arises from possible changes of non-CO\(_2\) forcings.

Until recently, it might have been feasible to stabilize global atmospheric CO\(_2\) levels to at 350 parts per million. For this, humanity should have reduced emissions in a way consistent with the best climate science estimates of the global greenhouse gas budget. In addition, measures could have been taken to store considerable quantities of CO\(_2\) in the biosphere, which could have been accomplished, for instance by improved agricultural practices,\(^{86}\) reforestation, and ecosystem restoration around the world. Currently, CO\(_2\) stabilization at 350 parts per million requires unprecedented global efforts and/or unparalleled, large-scale negative emissions.\(^{87}\) Moreover, the technologies that have been proposed for scrubbing CO\(_2\) from the atmosphere, still present serious practical obstacles, while—as with any new technology—there is the danger of both foreseeable and unforeseeable adverse impacts that would themselves require remediation.\(^{88}\)

A recent report by the European Academies Science Advisory Council (EASAC) has the following, sobering comment about negative emissions:\(^{89,90}\)

One factor possibly contributing to a lack of urgency may be the belief that somehow ‘technology’ will come to the rescue. The present report shows that such expectations may be seriously over-optimistic. Intergovernmental Panel on Climate Change (IPCC) future scenarios allow Paris targets to be met by deploying technologies that remove carbon dioxide from the atmosphere. However, putting a hypothetical technology into a computer model of future scenarios is rather different than researching, developing, constructing and operating such a technology at the planetary scale required to compensate for inadequate mitigation.

More explicitly stated, there is no excuse for inadequate mitigation.

Moreover, it has also been clear for some time that the widespread, near-exclusive focus on CO\(_2\) emissions is misguided and, in fact, constitutes a violation of the precautionary principle\(^{91}\) as mentioned in section A.11.1 on page 138. Reduction of CO\(_2\) by substituting combustion of natural gas for burning of coal and oil, as proposed in the Obama adminis-

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\(^{86}\)Beerling et al., supra note 62.

\(^{87}\)Hansen et al., “Young people’s burden: requirement of negative CO\(_2\) emissions,” supra note 37.


\(^{90}\)Also see Vaughan and Gough, supra note 63, Rabinowitz and Simson, supra note 67, and Kolbert, supra note 66.

\(^{91}\)Principle 15 of the supra note 80.
tration’s President’s Climate Action Plan\textsuperscript{92} is a policy that runs the serious risk of setting off catastrophic, run-away, on a human timescale irreversible climate change. The reason for this is that the 350 parts per million CO\textsubscript{2} target fails to account for the observed, vast increase of CH\textsubscript{4}, a greenhouse gas much more potent than CO\textsubscript{2}. section A.9 discusses some of the serious misrepresentations that have given rise to a dangerously misguided state and national energy policy.

Humanity should do all possible to ward off the severe impacts of climate destabilization. The 350 parts per million CO\textsubscript{2} target, inadequate as it may be, is required by the current climate emergency. This target is a global average that does not account for the different responsibilities of individual states and nations in view of their historic contribution to greenhouse gas pollution. Some of the national security and geopolitical ramifications of this global nature of the climate change problem are discussed in section A.8, page 116. In terms of responsibilities it should be stressed, as mentioned above, that “poorest countries will suffer the greatest consequences of climate change even though they contributed the least for emissions.”\textsuperscript{93}

In this context it should be noted, as Hansen and Sato observe, that:\textsuperscript{94}

There is striking incongruity between the global distribution of nations principally responsible\textsuperscript{95} for fossil fuel CO\textsubscript{2} emissions, known to be the main cause of climate change, and the regions suffering the greatest consequences from the warming, a fact with substantial implications for global energy and climate policies.

Fig. 1 is pertinent to the issue of responsibilities.\textsuperscript{96}


\textsuperscript{93} supra note 83, p. 1700.


\textsuperscript{95} Also see Fig. 22 and its lead-in on page 120.

\textsuperscript{96} Hansen and Sato, supra note 94, see their Fig. 5.
Science unequivocally shows that climate change is predominantly anthropogenic and a threat to the biosphere as a whole. Climate change is already occurring in Rhode Island; it is projected to impact the state more significantly in the future, as discussed in section A.2, page 30.

There are ways of stabilizing the global climate system, but the pace at which humanity is implementing these is inadequate. As a consequence, the associated cost and severity of the inescapable disasters are mounting at an ever-increasing, literally exponential pace.

In this context, as far as Rhode Island is concerned, the following plan of the Executive is irreconcilable with the grave climate danger connected with the considerable fraction of natural gas that escapes unburned, aka fugitive methane, as discussed in detail in section A.9, page 122.

The Rhode Island Office of Energy Resources in its 2015 Zero Emissions Vehicle Action Plan states:  

In 2013 the State also initiated a “Lead by Example” which requires any new state fleet vehicle (to the extent practical) to be electric, hybrid, or compressed natural gas.

As to the last item just mentioned, we draw attention to a study of natural gas vehicles. The finding is that they do not reduce greenhouse gas emissions, even when a large fraction of the emissions is ignored. To wit, the study does not account for the full “well-to-wheels” propulsion life-cycle and considers only its last “pump-to-wheels” segment.  


99 N. N. Clark et al., “Future methane emissions from the heavy-duty natural gas transportation sector for stasis, high, medium, and low scenarios in 2035.” In: Journal of the Air & Waste Management Association
Governor Gina Raimondo in a press release dated April, 20, 2015 was quoted saying:\supra note 73.

I am committed to moving ahead with cost-effective, regional energy infrastructure projects—including expansion of natural gas capacity—that will improve our business climate and create new opportunities for Ocean State workers.

A Rhode Island Public Radio report, discussing an exchange with CEO Polsky of Invenergy LLC, the company proposing to build a fossil-fuel fired power plant in Burrillville stated that:\supra note 73.

Gov. Gina Raimondo joined Polsky to thank him for investing in Rhode Island.

“I know you have choices about where you could be and I’m pleased you’ve chosen Rhode Island and you should know we are going to make sure that you are successful here,” said the governor.

Seven months earlier, Polsky donated a $1,000 to the governor, the maximum annual legal limit from an individual to a political candidate.

The total energy used per capita in Rhode Island in 2015 according to the Energy Information Administration was 192 million Btu.\supra note 73. This amounts to a yearly mean total power consumption of 6 gigawatt. The Block Island wind farm has a nameplate rating of 30 megawatt. An optimistic estimate of actual, average power provided by the facility is roughly half of that. In other words, the wind farm supplies about a quarter of one percent of Rhode Island power. We do, however, note that the Energy Information Administration total quoted does not account for the energy spent on producing goods outside Rhode Island, e.g., in China or Japan and consumed in Rhode Island nor their transport. The “carbon leakage”\supra note 73 implies these “in-boundary production” numbers quoted by the Energy Information Administration fail to account for a substantial part, possibly as large as 50 percent, of actual “in-boundary consumption.”

Steinberger et al. have shown that “consumption-based emissions, which include the carbon embodied in all goods and services consumed in a country” better reflect the socio-economics of greenhouse gas emission than territorial (in-boundary) emissions.\supra note 73. We draw attention to the fact that the term consumption-based can be confusing. In contrast to the way the term is used in the 2016 Rhode Island Island Greenhouse Gas Emissions Reduction Rankings: Total Energy Consumed per Capita, 2015. U.S. Energy Information Administration. URL: https://www.eia.gov/state/rankings/?sid=RI#series/12 (visited on Dec. 25, 2017).


A SCIENTIFIC BACKGROUND—DETAILS

Plan\textsuperscript{106}, in which it is used for electricity generation exclusively, in this Petition we use it in a general sense, defined explicitly in section A.10, page A.10.

As far as Rhode Island’s impact on global warming and its contribution to global warming, the aforementioned plan is clearly little more than an “accounting trick,” as is clear from its footnote stating explicitly that “this Plan does not consider emissions associated with upstream impacts of energy resources or embodied energy.”\textsuperscript{107} Once again, we refer for further details to section A.10, page 133.

As to greenhouse gas emissions, if one correctly accounts the fugitive emissions of the natural gas consumed in the state the numbers are probably even more biased low—see section A.10, page 133.

As the Intergovernmental Panel on Climate Change (IPCC) uses the term, “[c]arbon leakage is defined as the increase in CO\textsubscript{2} emissions outside the countries taking domestic mitigation action divided by the reduction in the emissions of these countries.”\textsuperscript{108} In the context of this Petition, leakage is understood as applicable both to countries and states within the United States and to greenhouse gases in general, not just CO\textsubscript{2}.

It remains difficult to pin down the Rhode Island Executive, as the following two items show:

- In December of 2015, Governor Raimondo, in a challenge to state agencies to reduce energy consumption, issued her Lead by Example Executive Order. Part of this was that “[t]he State shall procure, subject to funding opportunities and constraints, 100\% of State government electricity consumption from renewable sources by 2025.”\textsuperscript{109}

- In March of 2017 Governor Raimondo announced a strategic goal of “1000 by ’20,” i.e., a gigawatt of clean energy by 2020.\textsuperscript{110}

Clearly, without an accounting system, an emissions inventory of in-boundary and consumption-based emissions accounting to hold the State accountable, the Petitioners will remain at peril.

A.2 Danger posed by climate change to the State of Rhode Island

In an undated, apparently decade-old presentation with compelling graphics and charts, Grover Fugate, Executive Director of Rhode Island Coastal Resource Management Council, summed up some of the climate change threats to the state as follows:\textsuperscript{111}


\textsuperscript{109}G. M. Raimondo, EXECUTIVE ORDER 15-17, STATE AGENCIES TO LEAD BY EXAMPLE IN ENERGY EFFICIENCY AND CLEAN ENERGY. State of Rhode Island and Providence Plantations. 2015. URL: http://www.governor.ri.gov/documents/orders/ExecOrder15-17.pdf, p. 2.


The frequency of tropical and extra-tropical storms is likely to increase in the future threatening an already vulnerable shoreline;

- Rising sea levels contribute to the net loss of shoreline, and threaten structures and infrastructure;
- Increasing rates of sea level rise in Rhode Island will likely result in wetlands loss and impacts to coastal ecosystems;
- The oceans will continue to warm for centuries, adding to sea level rise and impacting ecosystems.

In its 2016 report—of remarkably similar thrust—the Science and Technical Advisory Board (STAB) of the Rhode Island Executive Climate Change Coordinating Council (EC4) identified the following climate change threats to Rhode Island:\footnote{Current State of Climate Science in Rhode Island. Science and Technical Advisory Board (STAB) of the Rhode Island Executive Climate Change Coordinating Council (EC4), May 1, 2016. URL: http://climatechange.ri.gov/documents/ec4-science-and-technical-advisory-board-report.pdf (visited on Jan. 7, 2018), p. 1.}

1. Sea level rise
2. Warming air temperatures
3. Warming water (marine and fresh) temperatures
4. Storm frequency and intensity
5. Biodiversity (changes in species and habitats)
6. Precipitation and inland flooding

Here we present an overview of these threats, and, in addition, we address the following:

- Public health dangers in section A.2.5, page 37. These dangers particularly threaten children—see section A.2.5.2, page 39, for a general overview.

- Environmental justice issues related to storm surges that threaten the Port of Providence are summarized in section A.2.6, page 47. As is true both locally and globally, these dangers disproportionately affect the young and, as the demographic make-up of the neighboring Fields Point community in Providence shows. Indeed, “RI [p]olicy should prioritize vulnerable populations.”\footnote{Id., p. 6.}

- We note that, quoting from an Rhode Island Executive Climate Change Coordinating Council (EC4) report:\footnote{Id., p. 6.}

  Physical infrastructure is vulnerable, including roads due to increased frequency of freeze–thaw cycles. Electrical grids, power plants, and rail systems are also sensitive to heat as temperatures surpass 90 degrees F . . . .
A.2.1 Rhode Island sea level rise and inland flooding

Numerous reports document that sea level rise and inland flooding are affecting Rhode Island. As a direct consequence of the exponential growth of greenhouse gas emissions—as discussed in section A.3 and on page 54—sea level rise and inland flooding are projected to intensify. As the Environmental Protection Agency reported in 2016:\textsuperscript{115}

Rhode Island’s climate is changing. The state has warmed about three degrees (F) since the year 1900. Throughout the northeastern United States, spring is arriving earlier and bringing more precipitation, heavy rainstorms are more frequent, and summers are hotter and drier. Sea level is rising, and severe storms increasingly cause floods that damage property and infrastructure. In the coming decades, the changing climate is likely to increase flooding, harm ecosystems, disrupt fishing, and increase some risks to human health.

More specifically:\textsuperscript{116}

Rising temperatures and shifting rainfall patterns are likely to increase the intensity of both floods and droughts. Average annual precipitation in the Northeast increased 10 percent from 1895 to 2011, and precipitation from extremely heavy storms has increased 70 percent since 1958. During the next century, average annual precipitation and the frequency of heavy downpours are likely to keep rising.

A.2.1.1 Precipitation and inland flooding: As the 2016 report from the Science and Technical Advisory Board (STAB) to the Rhode Island Executive Climate Change Coordinating Council (EC4) mentions:\textsuperscript{117}

Climate change is expected to result in more frequent heavy rains, affecting stream flow in Northeastern states, with increases in 3-day peak flows contributing to increases in flooding risks (Demaria et al. 2015).\textsuperscript{[118]} Climate change may exacerbate drought conditions and reduce river and stream 7-day low flow events (Demaria et al. 2015). Southern RI, Block Island, Jamestown, and Aquidneck Island depend on shallow ground-water wells and shallow surface reservoirs, and are vulnerable to drought.

Rhode Island has experienced a significant increase in both flood frequency and flood severity over the past 80 years. RI and throughout most of southern New England has [sic] experienced a doubling of the frequency of flooding and an increase in the magnitude of flood events, (Vallee & Giuliano 2014) [broken link in reference; document can no longer be retrieved]. The NWS [National Weather Service] tracks flood severity by levels of minor, moderate and major.

We quote the following from the same 2016 report:\textsuperscript{119}


\textsuperscript{116} Id.

\textsuperscript{117} supra note 112, p. 14.


\textsuperscript{119} supra note 112, p. 3.
Between 1950–1979 and 1980–2009, the SLR [sea level rise] rate increase along this coastline was 3–4 times higher than the global average (Sallenger et al. 2012).\textsuperscript{120} Because of this factor, it is likely that this region, which includes Rhode Island, will see an additional 8 [0.2 m] to 11+ inches [0.3 m] above global average SLR [sea level rise] by 2100.

Once again illustrating how the actual pace of climate change is outpacing projections—see section A.11, page 138—a yet higher range of sea level rise was predicted in a January 2017 report by National Oceanic and Atmospheric Administration (NOAA).\textsuperscript{121}

Along regions of the Northeast Atlantic (Virginia coast and northward) and the western Gulf of Mexico coasts, RSL [relative sea level] rise is projected to be greater than the global average for almost all future GMSL [global mean sea level] rise scenarios (e.g., 0.3–0.5 m or more RSL [relative sea level] rise by the year 2100 than GMSL [global mean sea level] rise under the Intermediate scenario).

A.2.2 Narragansett Bay

As far as precipitation is concerned—as mentioned before and confirmed on page 66 in the material quoted from the Executive Summary of the 2017 Fourth National Climate Assessment—the “largest observed changes in the United States have occurred in the Northeast,” Also sea level rise is expected to affect the United States Northeast coast disproportionately—see section A.6.22.3, page 99; for potential surprises see section A.7.1, page 113.

As a 2017 Narragansett Bay report\textsuperscript{122} puts it: “the escalating impacts of climate change influence the bay’s ecosystem and public health conditions . . . ,”\textsuperscript{123} and:\textsuperscript{124}

[w]hile many people think of climate change as something that will happen in the future, substantial changes have already happened in the Narragansett Bay watershed—with more changes under way and more yet to come. Decades of scientific data show that local air and water temperatures have warmed, rainfall has increased in volume and intensity, and sea level has risen. Climate projections based on observed changes and numerical models, and tailored for the Narragansett Bay region, show that these changes will become more rapid.

That changes will become more rapid is of course a direct consequence of the exponential growth of greenhouse gases, discussed on page 53. Key conclusions of the report are:

- “Climate change is affecting air and water temperatures, precipitation, sea level, and fish in the Narragansett Bay region.”\textsuperscript{125}

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\textsuperscript{122}For the 2017 State of Narragansett Bay and Its Watershed technical report and related resources follow this link: http://nbep.org/the-state-of-our-watershed


\textsuperscript{124}Id., p. 20.

\textsuperscript{125}Id., p. 4.
• “Changes in climate such as increased rainfall, warmer water temperatures, and sea level rise are likely to exacerbate conditions leading to beach closures.”

The following correspond to sections of the report pertinent to climate change:

A.2.2.1 Warming temperatures trigger ecological changes:

Temperature strongly influences public health and environmental conditions in many ways. Decades of temperature measurements in Narragansett Bay and the watershed show that air and water temperatures are increasing.

As mentioned on page 66, life is more vulnerable to day-to-day fluctuations in temperature than to slow changes in its average. Recent research indicates that the risk of a heart attack increases by about 5 percent for every 5 °C temperature fluctuation.

A.2.2.2 Increasing precipitation and more intense storms:

Precipitation patterns are changing in the Narragansett Bay region. Average annual precipitation at Providence, Rhode Island, has increased by 0.4 inches per decade since 1895. Climate models project that annual precipitation will continue to increase by up to three inches per decade locally and that more precipitation will fall during intense storms, giving the ever-reducing areas of natural soils little opportunity to filter stormwaters.

A.2.2.3 Rising sea level will bring more flooding:

Measurements taken from 1930 to 2015 at a tide gauge at Newport, Rhode Island, show that sea level rose by nine inches during that 85-year period. Now the pace of sea level rise is increasing, carrying major implications for people, infrastructure, and habitats around Narragansett Bay.

A.2.2.4 Uncertain future for seagrass and salt marshes:

Recent observations and future projections suggest that a large percentage of existing marshes will be lost under accelerating sea level rise, affecting fish, birds, and wildlife of the Narragansett Bay region.
A.2.2.5 Warmer-water fish moving into the Bay.\textsuperscript{133}

In Narragansett Bay, warming of coastal waters—which has been documented here over the last 60 years and is projected to continue into the future—is an increasingly important factor. Since the 1980s, warmer-water species such as scup and black sea bass have displaced the resident species such as winter flounder and red hake, partly due to increasing temperatures. The survival rate of American lobster may also be reduced.

The impacts of global climate change on Narragansett Bay had already been reviewed in 2010 in a paper\textsuperscript{134} that mentions the effects of chronic eutrophication of Narragansett Bay compound the acidification due to the increased level of atmospheric CO\textsubscript{2}. The paper concludes that:\textsuperscript{135}

Narragansett Bay and coastal Rhode Island have been negatively affected by climate change, and these effects are likely to worsen as warming and CO\textsubscript{2} concentrations increase.

A.2.3 Increased incidence of harmful algal blooms

As Rhode Island Department of Environmental Management mentions\textsuperscript{136} harmful algal blooms tend to be restricted to late summer, when Narragansett Bay warms. Obviously, rising surface and ocean temperatures that result from climate change will extend this period and the frequency of these events, but also the expected increased levels of salinity and dissolved CO\textsubscript{2} will increase the danger.\textsuperscript{137} The following is a short description of the risks:\textsuperscript{138}

Harmful algal blooms may cause harm through the production of toxins or by their accumulated biomass, which can affect co-occurring organisms and alter food-web dynamics. Impacts include human illness and mortality following consumption of or indirect exposure to HAB toxins, substantial economic losses to coastal communities and commercial fisheries, and HAB-associated fish, bird and mammal mortalities.

A.2.4 Fisheries

The Environmental Protection Agency warns specifically of the danger that climate change poses to Rhode Island fisheries, in particular because of rising water temperature can lower oxygen levels:\textsuperscript{139}

\textsuperscript{133}\textit{supra} note 123, p. 24.
\textsuperscript{135}\textit{Id.}, p. 85.
\textsuperscript{136}\textit{Harmful Algal Blooms}. Rhode Island Department of Environmental Management. URL: \url{http://www.dem.ri.gov/programs/emergencyresponse/bart/habs.php} (visited on May 17, 2018).
\textsuperscript{138}This site is a comprehensive resource for information about harmful algal blooms: \textit{Harmful algae}. National Oceanic and Atmospheric Administration (NOAA)—Woods Hole Oceanographic Institution. URL: \url{http://www.whoi.edu/redtide/} (visited on May 17, 2018).
\textsuperscript{139}\textit{supra} note 115.
About half the species assessed are estimated to have a high or very high vulnerability to climate change in the region, including species like sea scallops, lobster, and winter flounder.\textsuperscript{140,141,142}

A 2008 detailed scientific study of Rhode Island fisheries reported in its \textit{technical} abstract that:\textsuperscript{143}

To study decadal shifts in a coastal nekton community, we analyzed data on 25 fish and invertebrate species collected from 1959 to 2005 by the University of Rhode Island, Graduate School of Oceanography (Narragansett, Rhode Island, USA). This weekly trawl survey samples two locations: inside Narragansett Bay and in Rhode Island Sound. Over four decades, the community has shifted progressively from vertebrates to invertebrates and, especially since 1980, from benthic to pelagic species. Demersal species that declined include winter flounder \textit{(Pseudopleuronectes americanus)}, silver hake \textit{(Merluccius bilinearis)}, and red hake \textit{(Urophycis chuss)}; meanwhile warm-water fish \textit{(butterfish, Peprilus triacanthus; scup, Stenotomus chrysops)} and invertebrates \textit{(lobster, crab, squid)} increased with time. Total numbers reached a maximum in the 1990s, while mean body size decreased. Taxonomic diversity increased over time, as the community shifted from fish to invertebrates of several phyla. The shifts in species composition correlate most strongly with spring–summer sea surface temperature, which increased 1.6 °C over the 47-year time series. Species composition was also correlated with the winter North Atlantic Oscillation index and chlorophyll concentration, which has declined since the 1970s. Triggered primarily by rising temperatures, these decadal changes have altered the trophic structure of the nekton community, resulting in a shift from benthic to pelagic consumers.

Also the projected increased storminess will increase the risks of what already is one of the most dangerous jobs on Earth.\textsuperscript{144} Furthermore, threats to fisheries have geopolitical ramifications—for more on this topic see section A.8, page 116.\textsuperscript{145,146}

Climate drivers are presenting new and unprecedented risks to fisheries, including increasing sea temperatures, ocean acidification, sea-level rise and changes to

\textsuperscript{142}See Figure 3.1 in \textit{supra} note 112, p. 8.
\textsuperscript{144}N. C. Sainsbury \textit{et al.}, “Changing storminess and global capture fisheries.” In: \textit{Nature Climate Change} (June 25, 2018). DOI: 10.1038/s41558-018-0206-x. url: https://doi.org/10.1038%2Fs41558-018-0206-x.
surface and deep water currents. These changes may could [sic] become a proximate cause and/or tipping point for resource conflicts as countries and companies pursue dwindling fish stocks that—accelerated by climate change—are also moving beyond sovereign Exclusive Economic Zones (EEZ) and traditional fishing grounds. Furthermore, conflict over fisheries in one part of the world can have impacts on regions and economies thousands of miles away, and are now central to understanding the unique security challenges of the Anthropocene.

Not only scientists and security experts are acutely aware of the precarious situation of global and Rhode Island fisheries, also the popular press is reporting about what Northeast fishermen are experiencing right now: 147

“There’s nothing here,” said Tomkiewicz, one of only 35 Massachusetts lobstermen who still have permits to fish in the state and federal waters that stretch from Nantucket Sound to Long Island Sound. “It’s crazy.”

This is from a recent study of how warming of the oceans induces shifts in the geographic distribution of marine species. Such shifts already pose challenges for fishery resource management: 148

Global ocean temperatures are projected to continue rising and areas of the Northeast American shelf may experience some of the most extreme increases [emphasis added]. Associated with this warming are predictions for substantial shifts in regional fisheries productivity. Predictions for how ocean warming will impact the living marine resources of the United States and Canada are currently a priority for federal management. [For references see original paper.]

A.2.5 Threats to Rhode Island public health

We can expect to have to deal with the following threats to public health in Rhode Island.

- West Nile is an urban-based virus, present in the United States, Europe, the Middle East, and Africa. “[W]arm winters and spring droughts play roles in amplifying this disease.” 149

- Lyme disease is a serious health threat exacerbated by climate change, as both Rhode Island Department of Health and Department of Environmental Management acknowledge 150. In fact, is the most widespread vector-borne disease in the United States. It

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can cause neurological damage and long-term disability.\textsuperscript{151,152} The disability affects approximately 300,000 Americans each year with boys 5 to 9 years of age at the greatest risk.\textsuperscript{153}

- Loss of biodiversity is occurring through climate change, which thereby increase the risk of tick-borne Lyme and mosquito-borne West Nile diseases mentioned in the previous two items.\textsuperscript{154} The Rhode Island Department of Health also mentions the increased risk of other illnesses in the latter category, such as Eastern Equine Encephalitis and Zika virus disease.\textsuperscript{155}

- Air quality is expected to diminish with climate change, leading to negative impacts on lung health. Ozone and CO\textsubscript{2} contribute to smog, which exacerbates asthma and chronic obstructive pulmonary disease.\textsuperscript{156} More CO\textsubscript{2} in the atmosphere may cause plants that produce allergenic pollens (\textit{e.g.} ragweed) to become more numerous and to produce greater quantities of pollen or pollen that is more allergenic.\textsuperscript{157}

- “Waste water collection systems typically experience spikes, of varying degrees, in flow rates during and following storm events.”\textsuperscript{158} Extreme rain events and sea level rise could overwhelm wastewater plants, leading to contamination of water supplies.\textsuperscript{159} In this context we note in particular the vulnerability for storm surges of the Fields Point Wastewater Treatment Facility.

- Indeed, as a Rhode Island Department of Environmental Management reports:\textsuperscript{160}

  With the propensity for wastewater treatment facilities and accompanying collection system components to be located at low elevations, wastewater infrastructure located in a coastal area is at serious risk for complete and permanent submersion.

- There are numerous waterborne organisms that endanger human health. Heavy rainfall, flooding, and increase in temperature associated with climate change has been observed to precede outbreak of the associated diseases.\textsuperscript{161} Intrusion of seawater into coastal groundwater, due to sea level rise, increases the risk of contamination of drinking water supplies.

\textsuperscript{151}Epstein and Mills, supra note 149, p. 9.
\textsuperscript{152}supra note 83, p. 1703.
\textsuperscript{154}supra note 83, p. 1704.
\textsuperscript{157}Id., p. 62.
\textsuperscript{159}Id., pp. 2.1,2.7.
\textsuperscript{160}Id., pp. 2-15.
\textsuperscript{161}P. R Hunter, “Climate change and waterborne and vector-borne disease.” In: Journal of Applied Microbiology 94 (2003), 37S–46S. DOI: 10.1046/j.1365-2672.94.s1.5.x. URL: http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2672.94.s1.5.x/epdf, 39S-40S.
The Environmental Protection Agency in 2016 issued a report focused specifically on Rhode Island. The report states:

Rhode Island’s climate is changing. The state has warmed about three degrees (F) since the year 1900. Throughout the north-eastern United States, spring is arriving earlier and bringing more precipitation, heavy rainstorms are more frequent, and summers are hotter and drier. Sea level is rising, and severe storms increasingly cause floods that damage property and infrastructure. In the coming decades, the changing climate is likely to increase flooding, harm ecosystems, disrupt fishing, and increase some risks to human health.  

A.2.5.1 Rhode Island Department of Health supplemental advisory opinion: Clear River Energy Center  
Rhode Island Department of Health statement for Energy Facility Siting Board:

RIDOH [Rhode Island Department of Health] continues to have grave concerns about climate change as a current and future health threat in Rhode Island and other locations and notes that vulnerable populations are already facing risks due to warming temperatures, impaired air quality, increased length and severity of pollen seasons, increasing severity of storms, flooding, drought, and the rising of sea levels. Health risks in Rhode Island associated with climate change include threats to housing and safety; heat-related morbidity and mortality; the introduction of infectious diseases and infectious disease vectors formerly confined to more southern latitudes; increase in symptoms of allergy, asthma and other respiratory diseases, and threats to the food and fresh water supply. As with many public health risks, people with limited means, people with compromised health and other susceptible populations, including the elderly, children and outside workers, are particularly vulnerable to those threats [emphasis added].

The Environmental Protection Agency in its 2016 report about Rhode Island mentions the danger of increased ground-level ozone (smog), which is known to increase the incidence of acute and chronic respiratory problems to which children, the elderly, the sick, and the poor are particularly vulnerable.  

A.2.5.2 Health of children and vulnerable populations  
Federal and state governments have been aware of the health issues associated with climate change for many years. The following is from the summary a 2016 report entitled Climate and Health Assessment a publication of the U.S. Global Change Research Program:

While all Americans are at risk, some populations are disproportionately vulnerable, vulnerable populations including those with low income, some communities of color, immigrant groups (including those with limited English proficiency),

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162 supra note 115.
164 supra note 115.
Indigenous peoples, children and pregnant women, older adults, vulnerable occupational groups, persons with disabilities, and persons with preexisting or chronic medical conditions.

The impact on children’s health, wellness, and safety is summed up by the American Public Health Association as follows: 166

**BACKGROUND ON CHILDREN’S HEALTH**

Children are especially vulnerable to climate change because of their physical and cognitive immaturity:

- Compared to adults, children breathe more air and drink more fluid for their body weight. Also, because they are shorter and spend more time on the ground, they are closer to ground-level pollutants. These factors cause children to have higher exposure levels than adults.
- Children engage in different behaviors from adults, including what they eat and activities such as crawling on the ground and hand-to-mouth activities. These behaviors make them more vulnerable to air, water, and soil exposures.
- Children have immature immune and organ systems. Thus, they are more sensitive to exposures that can cause permanent disabilities.
- Children are dependent on caregivers and may not be able to respond appropriately to threats. As a result, they are at risk of injury or even death in extreme weather emergencies.
- Children and adolescents engage in more outdoor activities than adults, leaving them more exposed to heat and outdoor air pollutants like ozone.

**FAST FACTS**

- Around 88% of the global disease burden of climate change falls on children under 5 years.
- Ozone is a known trigger for asthma attacks. Over 2 million children who suffer from asthma live in areas of the U.S. with unhealthy ozone levels [as reported] by the American Lung Association.
- Rates of heat-related death for infants under 1 year are 4 times as high as for persons 1–44 years old.
- After Superstorm Sandy, children living in homes with damage were over 5 times as likely to show signs of depression. They were over 8 times as likely to have difficulty sleeping and 5 times as likely to show signs of anxiety.

In 2016, the U.S. Environmental Protection Agency published a two-page fact sheet about the threat posed by climate change to children’s health. 167 As became clear preparing this


Petition, the current Administration is making it difficult to locate documents on EPA’s web site. Therefore, we include the fact sheet in this Petition on the following two pages. It mentions the the impacts of

- Air quality & respiratory illnesses
- Extreme weather events
- Heat-related illness; and
- Disease carried by ticks and mosquitoes

all of which are of immediate concern in Rhode Island.

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This fact sheet is based on “The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.” To explore the full report, go to:

https://health2016.globalchange.gov

Learn More

Climate Change and the Health of Pregnant Women
https://www3.epa.gov/climatechange/impacts/health/factsheets/

Climate Change: Human Health
https://www3.epa.gov/climatechange/impacts/health.html

Climate Change: What You Can Do
https://www3.epa.gov/climatechange/wycd/

Pediatric Environmental Health Specialty Units – expert medical advice on environmental exposures and health effects
www.pehsu.net

Tips from EPA’s Office of Children’s Health Protection
Protecting Children’s Environmental Health
https://www.epa.gov/children

How Caregivers Can Protect Children’s Health

Air Quality & Respiratory Illnesses
Check the Air Quality Index and pollen counts on your local weather reports and consider limiting outdoor time if levels are high.
www.epa.gov

Extreme Weather Events
If children are exposed to storms or floods, watch for diarrhea symptoms and mental health impacts. Also, watch for signs of mold indoors after a flood, and be sure to clean and dry affected areas. During a power outage, never use a generator indoors or in a garage.
http://emergency.cdc.gov/disasters

Heat-Related Illness
Watch for signs of dehydration or overheating: offer sips of water often and find places to cool off.
http://www.cdc.gov/heat/exercise.html

Disease Carried By Ticks and Mosquitoes
Prevent bites by using insect repellent (bug spray) and protective clothing (long sleeves and pants). Check children daily for ticks after they have been outdoors, especially in wooded or grassy areas and especially during warmer months.
https://www3.epa.gov/insect-repellents/
tips-prevent-mosquito-bites
https://www3.epa.gov/insect-repellents/
tips-prevent-tick-bites

Growing Bodies
Children’s growth and development from infancy to adolescence makes them more sensitive to environmental hazards related to climate. For example, because children’s lungs develop through adolescence, they are more sensitive to respiratory hazards. Climate change worsens air quality because warming temperatures make it easier for ground-level ozone to form. Changing weather patterns and more intense and frequent wildfires also raise the amount of pollution, dust, and smoke in the air. For children, this change in air quality may increase the number and worsen the severity of asthma episodes. Climate change is also expected to lead to longer and more severe pollen seasons, triggering asthma and allergies in children.

In addition to developing physically, children are also developing emotionally. Climate change will lead to an increase in the frequency, severity and duration of some extreme weather events, increasing risks to children’s mental health. When extreme weather causes injuries, death, or displacement, children may have difficulty controlling their emotions, may not perform as well in school, and may face depression, anxiety and post-traumatic stress. While many children show resilience to traumatic events, mental health impacts may last into adulthood, especially if left untreated.

What is climate change and why does it matter for health?

We’ve all heard of it, but what exactly is climate change? Greenhouse gases act like a blanket around Earth, trapping energy in the atmosphere. Human activities, especially burning fossil fuels for energy, increase the amount of greenhouse gases in our atmosphere and cause the climate to warm. Climate change refers to the typical or average weather for an area. Climate change is any change in average weather that lasts for a long period of time, like warming temperatures. Climate change affects the food we eat, the air we breathe, and the water we drink. It also leads to extreme weather events, like flooding, droughts, and wildfires. All of these impacts affect human health.

To protect children against the negative impacts of climate change, caregivers should consider the age, stage of development, and health of the children in their care and work with health professionals, educators, and others in the community to minimize exposure to environmental risks.
Unique Behaviors and Interactions with the Environment

Children's behaviors and interactions with the world around them increase their exposure to certain health threats. The graphic on the following page describes examples of how children's unique behaviors make them more vulnerable to certain health impacts that are expected to increase due to climate change.

Dependency on Adult Caregivers

Children, particularly those with disabilities or special health needs, must rely on parents or caregivers to provide for basic needs like nutrition, shelter, hygiene, and clothing. Children separated from their caregivers during weather events, such as during storms and floods, are at increased risk of health impacts.

Impacts as Children Grow

Climate change affects children differently depending on their age and stage of development. These stages begin in the womb and continue throughout childhood and adolescence. The graphic below provides some highlights of climate vulnerabilities at different stages of life.

Newborns

Newborns are more likely to have been born before their due date or at a low birth weight if their mother is exposed during pregnancy to extreme heat, air pollution, and flood-related contaminants.

Infants and Toddlers

Infants and toddlers breathe, eat, and drink more for their body size than adults. They are sensitive to pollutants or allergens in the air, which may trigger asthma episodes. Infants and toddlers are also sensitive to contaminants in water and food, which increases the risk of diarrhea. Heat-related illness is also a threat to very young children, as they are less able to regulate body temperature.

School Age and Older Children

School age and older children spend more time outdoors than adults, which increases their risk of being exposed to extreme heat and higher average temperatures, pollutants in air and water, and diseases carried by mosquitoes and ticks. High school athletes are particularly at risk for heat illnesses. About 9,000 children are treated for heat illness (such as heat stroke and muscle cramps) related to athletic activity each year.

Children's Exposure and Vulnerability to Climate Change Impacts

1. **Exposure to allergens**
   - Small children play on the ground and place their hands and other objects in their mouths. This increases their exposure to allergens such as dust, mold spores, and pollen.
   - Climate-related increases in droughts and dust storms can increase levels of dust.
   - More frequent extreme weather events such as flooding can lead to indoor mold growth.
   - Climate change leads to longer and more severe pollen seasons.

2. **Extreme heat**
   - Children and student athletes often play outside and may not recognize the signs of becoming dehydrated or overheated.
   - Children have a higher risk of becoming ill or dying due to extreme heat.
   - Climate change will increase extreme heat events and also lead to higher temperatures throughout the year.

3. **Insect and tick-related diseases**
   - Children spend more time outdoors than adults, increasing their exposure to mosquito and tick bites.
   - These bites can cause diseases that are diagnosed more often in children, such as La Crosse encephalitis or Lyme disease.
   - Climate change and increased temperatures will lead to insects expanding their ranges and being present for longer seasons.

4. **Contaminated water**
   - Children swallow about twice as much water as adults while swimming.
   - Children are more likely than adults to develop serious stomach and diarrheal illnesses if they drink contaminated water.
   - Climate change increases contamination risk in water bodies where children play.
   - Storms and floods may compromise local sources of drinking water.
A final, serious ethical concern for Rhode Island is that much of the natural gas used in Rhode Island is obtained from fracking. The dangers of this for children in particular have been documented by Concerned Health Professionals of New York.  

A.2.5.3 General human health Impacts The following is quoted from an editorial published in The Lancet, announcing the 2017 Lancet Countdown on health and climate: change.

The comprehensive Review describes the first results of a global initiative, which will annually report on indicators of climate change and its effects on health. One alarming finding is how rising temperatures have influenced the transmission of infectious diseases. Vectorial capacity of Aedes aegypti and Aedes albopictus has increased since 1990, with tangible effects—notably, the doubling of cases of dengue fever every decade since 1990. The report shows a 46% increase between 2000 and 2016 in the frequency of extreme weather events. The disparity in the resulting economic losses is clear, with proportional costs in low-income countries almost double to those in high-income countries.

Human-caused fossil fuel burning and the resulting climate change are already contributing to an increase in asthma, cancer, cardiovascular disease, stroke, heat-related morbidity and mortality, food-borne diseases, and neurological diseases and disorders.

While anthropogenic climate change threatens to undermine the past 50 years of gains in public health, the converse is that a comprehensive response to climate change could be “the greatest global health opportunity of the 21st century,” as states a November 2017 report in the prestigious medical journal The Lancet. The report states:

Climate change has serious implications for our health, wellbeing, livelihoods, and the structure of organised society. Its direct effects result from rising temperatures and changes in the frequency and strength of storms, floods, droughts, and heat waves—with physical and mental health consequences. The impacts of climate change will also be mediated through less direct pathways, including changes in crop yields, the burden and distribution of infectious disease, and in climate-induced population displacement and violent conflict. . . . Although many of these effects are already seen, their progression in the absence of climate change mitigation will greatly amplify existing global health challenges and inequalities.

172 Epstein and Mills, supra note 149, p. 42.  
174 Id., p. 3.
A recent study by Burke et al.\textsuperscript{175} predicts that unmitigated climate change (RCP8.5\textsuperscript{176}) could result in a combined 9–40 thousand additional suicides (95% confidence interval) across the U.S. and Mexico by 2050.

Droughts, floods, heat waves and other extreme weather events linked to climate change also lead to a myriad of health issues. The World Health Organization has stated that:\textsuperscript{177}

Infectious diseases take a heavy toll on populations around the world. Some of the most virulent infections are also highly sensitive to climate conditions. For example, temperature, precipitation and humidity have a strong influence on the reproduction, survival and biting rates of the mosquitoes that transmit malaria and dengue fever, and temperature affects the life-cycles of the infectious agents themselves. The same meteorological factors also influence the transmission of water and food-borne diseases such as cholera, and other forms of diarrhoeal disease.

Recent studies have highlighted the adverse mental health effects that result from climate change. One study noted that as many as 200 million Americans\textsuperscript{178} are expected to have mental health problems as a result of climate change and added that “inflicting the burden of climate change on the vulnerable is an immoral act that puts future generations in mortal danger.”\textsuperscript{179} Indeed mental health disorders are likely to be among the most dangerous indirect health effects of climate change.

The mental health effects can include elevated levels of anxiety, depression, PTSD, and a distressing sense of loss. The impacts of these mental health effects include chronic depression, increased incidences of suicide, substance abuse, and greater social disruptions like increased violence. The causal links are illustrated in Fig. 2.\textsuperscript{180}

A 2015 report in The Lancet states:\textsuperscript{181}

Involuntary displacement of populations as a result of extreme events has major public health and policy consequences. In the longer term, flooding affects perceptions of security and safety, and can cause depression, anxiety, and post-traumatic stress disorder.

The same report continues:\textsuperscript{182}

Climate change affects mental health through various pathways by inflicting natural disasters on human settlements and by causing anxiety-related responses,
Figure 2: An overview of the causal links between greenhouse gas emissions, climate change, and health.
and later chronic and severe mental health disorders, and implications for mental health systems. These effects will fall disproportionately on individuals who are already vulnerable, especially for indigenous people and those living in low-resource settings.

A.2.6  The Port of Providence

The Port of Providence, which according to the Energy Information Administration is a “key regional transportation and heating fuel products hub,” faces the increased danger of catastrophic storm surges. This is a quote from a storm resilience study of the Port of Providence:

The port is located at the northern end of Narragansett Bay, an ecologically sensitive estuary, that provides breeding grounds for marine life in the region. The length and orientation of Rhode Island’s Narragansett Bay, and its proximity to the Atlantic hurricane zone, make it susceptible to extreme storm surges from the southerly winds that are generated when a hurricane passes to the west of the Bay. As such, the United States Federal Emergency Management Agency (FEMA) considers Providence to be the “Achilles heel of the Northeast.” . . . The most recent major storm, Hurricane Carol in 1954, produced 5 m of storm surge in Providence. Most of the port lands in the study area are 1–3 m above mean high water. A 9-m hurricane barrier north of the port protects the downtown city area, but could result in higher storm surge levels at the port, as surge waters would accumulate in Providence Harbor instead of spreading throughout the low-lying region now protected inland of the barrier.

Fig. 3 shows how deep under water the Port of Providence would be in the event of a 6.4 meter (21 foot) storm surge. Because of toxic compounds stored in this area, a storm surge in this area could have a devastating effect on the communities in the neighborhood and on Narragansett Bay as a whole, as documented in great detail by the Environmental Justice League of Rhode Island in position paper entitled National Grid’s Liquefied Natural Gas (LNG) Liquefaction Facility: Toxic Hazards in the Port of Providence: Proposals for a

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183  supra note 72.
185  Id., p. 497.
Figure 3: Inundation levels along the Providence waterfront from the Fox Point Hurricane Barrier south to Fields Point and including the East Providence waterfront
Environmental Protection Agency’s EJSCREEN\(^{195}\) provides detailed statistics pertaining to environmental justice issues. The environmental indicators in Fig. 4, the demographic indicators in Fig. 5 and the environmental justice indicators in 6 clearly demonstrate the environmental justice dangers that threaten the community near the Port of Providence, which has a disproportionately large fraction of children under age five.

Figure 4: Fields Point environmental indicators from EJSCREEN. NATA stands for National Air Toxics Assessment.

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Figure 5: Fields Point demographics from EJSCREEN.

Figure 6: Fields Point environmental justice indicators from EJSCREEN.

**ENVIRONMENTAL JUSTICE AS A CIVIL RIGHT**

EPA defines environmental justice as “the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.” \footnote{Learn About Environmental Justice. United States Environmental Protection Agency. URL: https://www.epa.gov/environmentaljustice/learn-about-environmental-justice (visited on May 15, 2018).} ... Advocates for environmental justice argue that communities of color and poor communities have been disproportionately impacted by environmental injustices for decades. These advocates contend that it is not a coincidence that communities of color and poor communities “live, work[,] and play in America’s most polluted environments.”

More specifically the Environmental Protection Agency explains: \footnote{For more see, e.g., N. Oreskes, Testimony before the Committee on Environment and Public Works, United States Senate. Dec. 6, 2006. URL: https://web.stanford.edu/dept/cisst/ORESKES_Senate%20EPW_FINAL.pdf (visited on Apr. 17, 2018) and D. Wogan, Why we know about the greenhouse gas effect. 2013. URL: https://blogs.scientificamerican.com/plugged-in/why-we-know-about-the-greenhouse-gas-effect/ (visited on Nov. 1, 2017)}

Fair treatment means no group of people should bear a disproportionate share of the negative environmental consequences resulting from industrial, governmental and commercial operations or policies.

According to definition of the Environmental Protection Agency (1) the threat posed by climate change to the community near the Port of Providence in the event of a storm surge, (2) the failure of the State of Rhode Island to protect the neighboring community adequately, and (3) the potential of the Fox Point Hurricane Protection Barrier to exacerbate this danger surely raise serious questions about civil right violations and issues of environmental justice.

### A.3 Brief history and basics of climate science

The discovery of greenhouse gases and their scientific explanation started almost two centuries ago with Fourier’s prediction of global warming in 1827. \footnote{M. Marshall, Timeline: Climate Change. The New Scientist. 2006. URL: https://www.newscientist.com/article/dn9912-timeline-climate-change/ (visited on Oct. 23, 2017).} In fact, Fourier seems to have been the first to use the greenhouse analogy. \footnote{E. Foote, “Circumstances affecting the Heat of the Sun’s Rays.” In: American Journal of Science and Arts XXII (1856), pp. 382–383.} In 1856, Eunice Foote reported on her findings on “different circumstances that affect the thermal action of the rays of light that proceed from the sun.” \footnote{E. Foote, “Circumstances affecting the Heat of the Sun’s Rays.” In: American Journal of Science and Arts XXII (1856), pp. 382–383.} In 1863, Tyndall published a paper deepening this understanding.

In the 1890s, Arrhenius and Chamberlain independently considered the problems caused by the atmospheric buildup of CO$_2$ as the result of the increased combustion of fossil fuels.
Arrhenius and Chamberlain understood that the burning of fossil fuels could lead to global warming, but they did not realize that the process had already started.

In the 1950s, Revelle discovered that the oceans were absorbing far less than anticipated of the CO$_2$ humanity had been putting into the atmosphere since the Industrial Revolution.\textsuperscript{201}

Revelle chaired the Atmospheric Carbon Dioxide Subpanel of the Environmental Pollution Panel of Lyndon B. Johnson’s President’s Science Advisory Committee. Echoing Revelle’s comment of the mid 1950s, the 1965 report, \textit{Restoring the Quality of Our Environment}, states:\textsuperscript{202}

Through his worldwide industrial civilization, Man is unwittingly conducting a vast geophysical experiment.

In spite of the impression one might get from the public conversation in the United States, it is crystal clear that the United States Executive Branch has known about the effects and dangers of greenhouse gases for more than fifty years. Indeed, Revelle’s subpanel concluded its report with the following warning:\textsuperscript{203}

By the year 2000 the increase in atmospheric CO$_2$ will be close to 25%. This may be sufficient to produce measurable and perhaps marked changes in climate, and will almost certainly cause significant changes in the temperature and other properties of the stratosphere.

For a comprehensive history of the period from 1979–1989, well before the current politicization of the topic of climate change and its implications, we refer to a recent issue of the New York Times Magazine.\textsuperscript{204}

In 1958, Keeling\textsuperscript{205} had started monitoring atmospheric CO$_2$ levels continuously and found a regular yearly rise. As shown in Fig. 7, Keeling’s data and ice core data going back to decades before the Industrial Revolution perfectly form a single curve extending back to before the Industrial Revolution. Fig. 7 also shows, that the subpanel’s prediction was an underestimate: the 25% increase over the 280 parts per million CO$_2$ predating the Industrial Revolution, of approximately 280 parts per million\textsuperscript{206} 350 parts per million, was already reached in 1990, as the Environmental Protection Agency noted in its 1990 report.\textsuperscript{207} Such underestimated projections are a recurring theme in climate science with far-reaching and dangerous implications as discussed in detail in section A.11, page 138.
Figure 7: Keeling curve and ice core data: showing the steady increase in the concentration of CO\textsubscript{2} in the earth’s atmosphere

Keeling’s data—accurate to 0.1 parts per million per single measurement\textsuperscript{208}—show the seasonal modulations superimposed on the accelerating upward trend. Sixty years after the start of these measurements, atmospheric CO\textsubscript{2} continues to rise at an accelerating rate corresponding to exponential growth with a “compound interest” rate of more than 2% per year of the excess atmospheric CO\textsubscript{2} built up since the Industrial Revolution.

This rate of increase—not too far off from the 3.2% mentioned in the report to President Johnson\textsuperscript{209}—means, as the rule of 70 implies,\textsuperscript{210} that the atmospheric CO\textsubscript{2} content resulting from burning of fossil fuels doubles every three to four decades, corresponding to possibly a fourfold increase since Revelle first sounded the alarm in the 1950s.\textsuperscript{211} Nonetheless, very little progress has been made since the 1960s, as witnessed by this statement issued by world-class scientists and more than 15,000 scientist signatories from almost 200 countries:\textsuperscript{212}

[A] great change in our stewardship of the Earth and the life on it is required, if vast human misery is to be avoided.

CO\textsubscript{2} emissions have been the predominant driver of global warming; both cause and effect, are shown in Tab. 2. Indeed, the temperature increase, shown as the temperature anomaly\textsuperscript{213} in Fig. 9, tracks the climate forcing resulting from the increase in atmospheric CO\textsubscript{2} as caused by carbon dioxide emissions dating back to the beginning of the Industrial Revolution. The data shown in Fig. 8 comes from the Carbon Dioxide Information Analysis

\textsuperscript{208} supra note 58.
\textsuperscript{209} Id., p. 119.
\textsuperscript{210} The rule of 70 says that at a compound interest rate of 1% per year an investment capital will double in 70 years. At a rate of 2% it takes 35 years, etc. This rule applies to small interest rates, but at 10% it still is quite accurate and gives a doubling time of seven years, while the more accurate time is 7.3 years.
\textsuperscript{211} The emissions curve as a function of time \(t\) is given by \(C_{\text{global}}(t) = 9.0 \exp[0.025(\frac{t}{\text{year}} - 2010)] \text{GtC/} \text{year}
\textsuperscript{213} The term temperature anomaly denotes the deviation of the temperature from a suitably chosen baseline.
As Figs. 8 and 9 in Tab. 2 show, the data can be represented by a simple exponential growth curve showing a growth of emissions of 2.5% per year. Although one expects yearly fluctuations, the warmest years in the 137-year record have all occurred since 1999. The probably of that having occurred purely by chance is smaller than one in $10^{21}$, that is ten million cubed. The year 2016 ranks as the warmest on record.

<table>
<thead>
<tr>
<th>Table 2: Global CO$_2$ emissions and the temperature anomaly, the change in the global surface temperature relative to 1951–1980 average temperature, are on a trajectory of exponential growth (“compound interest”) curves with an increase of 2.5% (“interest rate”) per year.</th>
</tr>
</thead>
</table>

The order of magnitude of the rate of increase of the recent temperature anomaly agrees with estimates of a comprehensive study featuring surface temperature reconstruction estimates. We reproduce Figure S1 of the corresponding report here in our Fig. 10.

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215The temperature anomaly at time $t$ is given by $\Delta T(t) = -0.31^\circ C + 1.01^\circ C \exp[0.025(\frac{t}{\text{year}} - 2010)]$.


217The temperature data in Fig. 9 are from Id.

218We count 137, not 136, years in the period 1880–2016 and 18 (not 17) years in the period 1999–2016; Id.

219Surface temperature reconstructions for the last 2,000 years. Board on Atmospheric Sciences, Climate, Division on Earth, and Life Studies, National Research Council of the National Academies. 2006. URL: https://www.nap.edu/read/11676/chapter/1, p. 5.
Figure 10: This set of reconstructions conveys a consistent picture of temperature changes over the last 1,100 years and especially over the last 400.

All of the above incontrovertibly supports the following conclusion:

Multiple lines of independent evidence confirm that human activities are the primary cause of the global warming of the past 50 years. The burning of coal, oil, and gas, and clearing of forests have increased the concentration of carbon dioxide in the atmosphere by more than 40% since the Industrial Revolution, and it has been known for almost two centuries that this carbon dioxide traps heat.

A.4 Earth’s climate, complex systems, and quantitative predictability

The earth’s climate is driven by energy from the sun passing through it. It is well-known that such forced system can display a rich variety of spontaneously appearing, spatiotemporal structures. Except under well-controlled circumstances of laboratory experiments, the ability of science to make accurate, quantitative predictions about such features is quite limited. It is this limitation that makes the precautionary principle a recurring theme in considering climate change policies and responsibilities. Indeed, the global weather system displays many such structures, such as the jet stream, its substructures, meanders known as Rossby

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220 Melillo, Richmond, and Yohe, supra note 77.
222 Principle 15 of the supra note 80.
waves, hurricanes, tornadoes, and virtually anything that has a name on a meteorologist’s map.

Another feature that limits accurate predictability is that global climate system has a wide range of characteristic timescales:

- At the short end of the scale there are lightning bolts and squalls;
- Heat waves and cold snaps on the scale of weeks;
- The seasons;
- El Niño-Southern Oscillation on the scale of three to seven years;
- The eleven-year Sun spots;
- The Pacific Decadal Oscillation;
- The Atlantic Multi-Decadal Oscillation;
- The Milankovitch Ice Age Cycles at the long 10,000–100,000 year end of the timescale.

Similarly, there are many different length scales involved anywhere in the range from several kilometers, the scale of a micro-burst, to tens of thousands of kilometers, the scale of the circumference of the earth.

There are also many participating “players” from volcanoes to humanity itself since the Industrial Revolution, the beginning of the latest geological period, the Anthropocene. The wide range of spatial and temporal scales together with the many interacting components make the global climate system the epitome of a complex system, which displays what ecologists call disturbances, i.e., fairly discrete, natural or human-caused events in time or space that disrupt the ecosystem. Similar disturbances occur as part of the weather system: wildfires—see section A.6.17 such events are known as state shifts, tipping points, or instabilities. Examples of these are the disintegrating sea-based ice shelves and land-based ice sheets, as discussed in detail in sections A.6.22 and A.6.23.

Disturbances can be relatively short-lived but may have long-lasting effects, as was the case in the Permian-Triassic extinction, aka the Great Dying, that happened 250 million years ago. It led to the death of more than 95% of marine invertebrates and 75% of terrestrial species, and was of a “truly singular and irreversible nature.”

This Great Dying has been associated with the methane put into the atmosphere by the disruption of the carbon

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cycle that brought about the emergence of a new microbial metabolic pathway efficiently converting marine organic carbon to methane.

Another dramatic example of a disturbance was the Cretaceous-Tertiary mass extinction of three-quarters of the plant and animal species on earth. It occurred over a geologically short period of time as a consequence of a six to nine month atmospheric blackout followed by a 50% drop in solar heating that lasted for about a decade.227

Bond et al. review almost twenty ecological crises roughly in the range from 600 million too 100 million year ago and explore their possible causes. Most extinctions are associated with global warming and related killers such as lack of oxygen in the oceans.228

We refer to a non-technical article in Cosmos,229 of which Tab. 3 is a summary.

Table 3: Five mass extinctions. The Permian-Triassic extinction is also known as the Great Dying.

<table>
<thead>
<tr>
<th>period</th>
<th>million years ago</th>
<th>species lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordovician-Silurian</td>
<td>450</td>
<td>85%</td>
</tr>
<tr>
<td>Late Devonian</td>
<td>375</td>
<td>75%</td>
</tr>
<tr>
<td>Permian-Triassic</td>
<td>250</td>
<td>95%</td>
</tr>
<tr>
<td>Triassic-Jurassic</td>
<td>200</td>
<td>80%</td>
</tr>
<tr>
<td>Cretaceous-Tertiary</td>
<td>70</td>
<td>75%</td>
</tr>
</tbody>
</table>

As Hansen has stressed230 humanity is currently causing a disturbance of the biosphere of a magnitude comparable to the causes of these mass extinctions. More than a decade ago, mincing no words, Hansen wrote:231

> On a slippery slope to Hell, a stream of snowmelt cascades down a moulin on the Greenland ice sheet. The moulin, a near-vertical shaft worn in the ice by surface water, carries water to the base of the ice sheet. There the water is a lubricating fluid that speeds motion and disintegration of the ice sheet. Ice sheet growth is a slow dry process, inherently limited by the snowfall rate, but disintegration is a wet process, spurred by positive feedbacks, and once well underway it can be explosively rapid [emphasis added].

As is clear from the exponential increase in atmospheric CO$_2$ discussed in section A.3, page 53, humanity has perturbed the climate system in a way that shows exponential increase since the Industrial Revolution. The term *perturbation* is used here in the technical sense meaning that humanity has imposed on the climate system a departure from the trajectory it has been on during the Holocene, i.e. the last 12,000 years.

Current global mean temperature increase is close to—and probably slightly above—the maximum warming of the Holocene era, as shown in Fig. 12, the period of a relatively

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231Id.
stable climate over the last 10,000 years during which human civilization developed. To be specific:\textsuperscript{232,233}

Global warming in the past 50 years has raised global temperature well above the prior range in the Holocene (the current interglacial period, approximately the past 11,700 years) to the level of the Eemian period (130,000 to 115,000 years ago), when sea level was 6–9 meters (20–30 feet) higher than today.

The growth rate of greenhouse gas climate forcing has accelerated markedly in the past several years (Fig. 3) [here Fig. 11], a conclusion starkly at odds with the common narrative that the world has recently turned the corner toward a solution of the global warming problem.

Figure 11: Recent growth rate of total greenhouse gas climate forcing. Points are 5-year running means, except for 2015, which is a 3-year mean.

In this context we draw attention to a recent review article reaching the similar conclusions.\textsuperscript{234} Also of relevance in this context is the following:\textsuperscript{235}

Major abrupt shifts occurred in the climate of ancient northern Europe, according to a new study. The research reports that sudden cold spells, lasting hundreds of years, took place in the middle of the warm Eemian climate period, about 120,000 years ago.


\textsuperscript{233}Hansen \textit{et al.}, “Young people’s burden: requirement of negative CO\textsubscript{2} emissions,” \textit{supra} note 37.


For further details pertaining to the related slowdown of the North Atlantic circulation see section A.7.1, page 113.

We stress in this context that:

Before the last ice age began 130,000–115,000 years ago, for instance, sealevels were 6–9 metres higher than today—yet atmospheric carbon-dioxide levels were about 30% lower. And 3 million years ago, when CO$_2$ levels roughly equaled today’s, the oceans may have been 10–30 metres higher.

Not only will sea level rise of this magnitude devastate coastal regions, it is a threat to the very fabric of society on a global scale. In this context we mention the threats to international security, as predicted by experts and as discussed in more detail in section A.8, page 116.

In Fig. 12 we reproduce Fig. 3.b of Hansen et al. (We refer to the original for the reference in the caption.)

Figure 12: Centennially smoothed Holocene temperature (Marcott et al., 2013) and 11-year running mean of modern temperature as anomalies relative to 1880–1920.

By zeroing in on the last millennium, one sees that during the last century the earth has warmed at a rate “roughly ten times faster than the average rate of ice-age-recovery warming,” as Fig. 13 shows.

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Figure 13: Temperature histories from paleoclimate data (green line) compared to the history based on modern instruments (blue line) shows that global temperature is warmer now than it has been in the past millennium, possibly longer.

Figs. 12 and 13 provide the background that makes it possible to appreciate the significance of the global temperature increase, and to understand its sixty-year old characterization of the temperature increase by Revelle as a “large-scale geophysical experiment.”

As the Intergovernmental Panel on Climate Change (IPCC) sums it up in its fifth, 2013 assessment report:240

The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C, over the period 1880 to 2012, when multiple independently produced data sets exist. The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 [0.72 to 0.85] °C, based on the single longest data set available . . . .

If the climate system were simple, this would imply a departure from that trajectory that grows exponentially in time, given the expected surprises discussed in section A.6.27. “Expected surprises” may sound as a contradiction in terms; it is not. This means that science can predict that there are tipping points, but it can predict only very roughly when the climate system will pass those and undergo a “notoriously difficult to foresee,” irreversible tipping point.241

To use this lack of accurate predictability as an excuse for inaction clearly is a reversal of the burden of the proof and a patent violation of the Precautionary Principle 15 of the Rio Declaration.242

A.5 Progress in attribution of events to climate change

How can one objectively ascertain that extreme events, such as the devastating hurricanes and wild fires of 2017 or particular instances of heat waves were caused by climate change?

As Intergovernmental Panel on Climate Change (IPCC) notes in its fifth and latest assessment report, aka AR5:243


241Drijfhout et al., supra note 61.

242supra note 80.

It is extremely likely that human activities caused more than half of the observed increase in GMST [Global mean surface temperature] from 1951 to 2010. This assessment is supported by robust evidence from multiple studies using different methods.

A study 2007 study already reported that:\(^{244}\)

the fraction of the globe that has observed significant warming trends on both annual and winter-mean timescales exceeds that which may be attributed to internal climate variability alone.

In 2012 Coumou and Rahmstorf noted that “[T]here is now strong evidence linking specific events or an increase in their numbers to the human influence on climate.” Indeed:\(^{245}\)

In a stationary climate, the number of threshold-exceeding extremes should remain constant over time.\(^{246}\) Therefore, if a trend is detected in their number then this can be attributed to non-stationarity, that is, climatic change.

This study concluded that:\(^{247}\)

Many lines of evidence—statistical analysis of observed data, climate modeling and physical reasoning—strongly indicate that some types of extreme events, most notably heatwaves and precipitation extremes, will greatly increase in a warming climate and have already done so.

Hansen, Sato, and Ruedy studied changes that have occurred in frequency of extremes. They conclude that:\(^{248}\)

An important change is the emergence of a category of summertime extremely hot outliers, more than three standard deviations (3\(\sigma\)) warmer than the climatology of the 1951–1980 base period. This hot extreme, which covered much less than 1% of Earth’s surface during the base period, now typically covers about 10% of the land area. It follows that we can state, with a high degree of confidence, that extreme anomalies such as those in Texas and Oklahoma in 2011 and Moscow in 2010 were a consequence of global warming because their likelihood in the absence of global warming was exceedingly small.

High-impact weather events have led to the emergence of a new branch of science: extreme-event attribution:\(^{249}\)


\(^{246}\)Added note: the term “stationarity” is used to indicate that the statistical properties of the system do not change over time or do so periodically daily, seasonally, etc. Some use the term “equilibrium” to mean the same.

\(^{247}\)Coumou and Rahmstorf, supra note 245, p. 494.


The detection and attribution of long-term trends in observed records (mainly temperature) has been routinely carried out at least since the second IPCC (Intergovernmental Panel on Climate Change (IPCC)) report in 1995. But attributing individual extreme events was deemed impossible until later, when the theoretical possibility was first described . . . and then applied to show that the likelihood of the European heatwave of 2003 was at least doubled due to human influence . . .

An intense, nearly continuous precipitation event occurred in Louisiana in August of 2016. It caused serious flooding and quickly resulted in the following study:250

The objective of this study is to show the possibility of performing rapid attribution studies when both observational and model data and analysis methods are readily available upon the start. It is the authors’ aspiration that the results be used to guide further studies of the devastating precipitation and flooding event. Here, we present a first estimate of how anthropogenic climate change has affected the likelihood of a comparable extreme precipitation event in the central US Gulf Coast.

The following illustrates how rapidly the science of extreme-event attribution is developing:251

This sixth edition of explaining extreme events of the previous year (2016) from a climate perspective is the first of these reports to find that some extreme events were not possible in a preindustrial climate.

... Of the 131 papers [emphasis added] now examined in this report over the last six years, approximately 65% have identified a role for climate change, while about 35% have not found an appreciable effect.

A recent study of the cause of the extremely high Arctic surface temperature in 2016 concluded that most of it was likely attributable to human-induced climate change.252

Finally, we mention that also the occurrence of cold extremes has been linked to climate change. This has been linked in particular to the “[m]ore-persistent weak stratospheric polar vortex,” which has been observed over the last decades.253 The increased magnitude of extreme cold snaps may seem counter-intuitive, but it is a direct consequence of the build-up of greenhouse gases. This boosts the energy present in the climate system, which in turn enhances volatility and temperature excursions in either direction away from the mean.

As a result, and because extreme weather events tend to coincide with planetary-scale wave distortions propagating along edge of the jet stream, aka the tropospheric polar vortex, the term polar vortex has become part of the popular culture.

This recent publication confirms the increasing trend of extreme winter weather in particular in the eastern U.S.:

We also show that during mid-winter to late-winter of recent decades, when the Arctic warming trend is greatest and extends into the upper troposphere and lower stratosphere, severe winter weather—including both cold spells and heavy snows—became more frequent in the eastern United States.

A.6 United States global research program

A.6.1 Introduction

The United States Global Change Research Program dates back to 1989. It was established to “assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change.”

The legal mandate reads:

The U.S. Global Change Research Program (USGCRP) was established by Presidential Initiative in 1989 and mandated by Congress in the Global Change Research Act (GCRA) of 1990 to develop and coordinate “a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change.”

This section summarizes key findings of the United States Global Research Program with an emphasis on the most recent, 2017 Fourth National Climate Assessment, which is the first of two volumes. The second one will be released at the end of 2018 and will contain regional chapters and “Climate Effects on U.S. International Interests.” In this chapter we have a separate section A.8, page 116, dealing with national security and geopolitics.

To make up for the incompleteness of the Fourth National Climate Assessment, besides cross-references to other sections (usually identified as “editorial” comments in square brackets) additional information, drawn from other sources, is interpolated in separate subsections.

Volume I of the Fourth National Climate Assessment states:

This report is an authoritative assessment of the science of climate change, with a focus on the United States. It represents the first of two volumes of the Fourth National Climate Assessment, mandated by the Global Change Research Act of 1990.

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257 supra note 60.

Here is a list of relatively recent assessments in this series:

1. *First National Climate Assessment*, 2000;
2. *Second National Climate Assessment*, 2009;
3. *Third National Climate Assessment*, 2014;
4. *Fourth National Climate Assessment*, 2017

**A.6.2 Third National Climate Assessment: key messages for the Northeast**

These are 2014 regional highlights for the United States Northeast:

**Key Messages**

- Heat waves, coastal flooding, and river flooding will pose a growing challenge to the region’s environmental, social, and economic systems. This will increase the vulnerability of the region’s residents, especially its most disadvantaged populations.
- Infrastructure will be increasingly compromised by climate-related hazards, including sea level rise, coastal flooding, and intense precipitation events.
- Agriculture, fisheries, and ecosystems will be increasingly compromised over the next century by climate change impacts. Farmers can explore new crop options, but these adaptations are not cost- or risk-free. Moreover, adaptive capacity, which varies throughout the region, could be overwhelmed by a changing climate.
- While a majority of states and a rapidly growing number of municipalities have begun to incorporate the risk of climate change into their planning activities, implementation of adaptation measures is still at early stages.

**A.6.3 Third National Climate Assessment: Indigenous Peoples**

The *Third National Climate Assessment* of 2014 has a chapter devoted to “multiple social and ecological challenges arising from climate impacts on indigenous communities . . . .”

The peoples, lands, and resources of indigenous communities in the United States, including Alaska and the Pacific Rim, face an array of climate change impacts and vulnerabilities that threaten many Native communities. The consequences of observed and projected climate change have and will undermine indigenous ways of life that have persisted for thousands of years. Key vulnerabilities include the loss of traditional knowledge in the face of rapidly changing ecological conditions,

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259 Melillo, Richmond, and Yohe, supra note 77.
increased food insecurity due to reduced availability of traditional foods, changing water availability, Arctic sea ice loss, permafrost thaw,\textsuperscript{263} and relocation from historic homelands. . . .

Climate change impacts on many of the 566 federally recognized tribes and other tribal and indigenous groups in the U.S. are projected to be especially severe, since these impacts are compounded by a number of persistent social and economic problems.

\textbf{A.6.4 Fourth National Climate Assessment executive summary}\textsuperscript{264}

The following is from the Executive Summary of the most recent, 2017, Fourth National Climate Assessment:\textsuperscript{265}

Global annually averaged surface air temperature has increased by about 1.8 °F (1.0 °C) over the last 115 years (1901–2016). \textbf{This period is now the warmest in the history of modern civilization.} [Original emphasis, here and in the rest of this Executive Summary. For a more precise, quantitative statement of the facts see Fig. 12.] The last few years have also seen record-breaking, climate-related weather extremes, and the last three years have been the warmest years on record for the globe. These trends are expected to continue over climate timescales. [NASA makes a much stronger statement;\textsuperscript{266} also see note 218.]

This assessment concludes, based on extensive evidence, that it is extremely likely that human activities, especially emissions of greenhouse gases, are the dominant cause of the observed warming since the mid-20th century. For the warming over the last century, there is no convincing alternative explanation supported by the extent of the observational evidence.

In addition to warming, many other aspects of the global climate are changing, primarily in response to human activities. \textbf{Thousands of studies conducted by researchers around the world have documented changes in surface, atmospheric, and oceanic temperatures; melting glaciers; diminishing snow cover; shrinking sea ice; rising sea levels; ocean acidification; and increasing atmospheric water vapor.}\textsuperscript{267}

For example, \textbf{global average sea level has risen by about 7–8 inches since 1900, with almost half (about 3 inches) of that rise occurring since 1993. Human-caused climate change has made a substantial contribution to this rise since 1900, contributing to a rate of rise that is greater than during any preceding century in at least 2,800 years. Global sea level rise has already affected the United States;}

\textsuperscript{263}Northern Hemisphere permafrost soils contain nearly twice as much Hg as all other soils, the ocean, and the atmosphere combined, indicating a need to reevaluate the role of the Arctic regions in the global Hg cycle. (P. F. Schuster \textit{et al.}, “Permafrost Stores a Globally Significant Amount of Mercury.” In: \textit{Geophysical Research Letters} [], pp. 1–9. ISSN: 1944-8007. DOI: \url{10.1002/2017GL075571}. URL: \url{http://onlinelibrary.wiley.com/doi/10.1002/2017GL075571/epdf})

\textsuperscript{264}Wuebbles \textit{et al.}, “Executive summary,” supra note 84.

\textsuperscript{265}\textit{Id.}

\textsuperscript{266}NASA, supra note 216.

\textsuperscript{267}\textit{Greenhouse Gasses—Water Vapor}. NOAA—National Centers for Environmental Information. URL: \url{https://www.ncdc.noaa.gov/monitoring-references/faq/greenhouse-gases.php?section=watervapor} (visited on Dec. 17, 2017), Water vapor is the most abundant greenhouse gas of all; its density in the atmosphere is determined primarily by temperature and not by human emissions. For that reason it is not usually listed as a greenhouse gas.
the incidence of daily tidal flooding is accelerating in more than 25 Atlantic and Gulf Coast cities.

Global average sea levels are expected to continue to rise—by at least several inches in the next 15 years and by 1–4 feet by 2100. A rise of as much as 8 feet by 2100 cannot be ruled out. Sea level rise will be higher than the global average on the East and Gulf Coasts of the United States.[See section A.7.1]

Changes in the characteristics of extreme events are particularly important for human safety, infrastructure, agriculture, water quality and quantity, and natural ecosystems. Heavy rainfall is increasing in intensity and frequency across the United States and globally and is expected to continue to increase. The largest observed changes in the United States have occurred in the Northeast.

Heatwaves have become more frequent in the United States since the 1960s, while extreme cold temperatures and cold waves are less frequent. Recent record-setting hot years are projected to become common in the near future for the United States, as annual average temperatures continue to rise. Annual average temperature over the contiguous United States has increased by 1.8°F (1.0°C) for the period 1901–2016; over the next few decades (2021–2050), annual average temperatures are expected to rise by about 2.5°F for the United States, relative to the recent past (average from 1976–2005), under all plausible future climate scenarios. [Average temperatures are important, but life is particularly vulnerable for spatial and temporal excursions about the average; see the reference in note 94 for more.]

The incidence of large forest fires in the western United States and Alaska has increased since the early 1980s and is projected to further increase in those regions as the climate changes, with profound changes to regional ecosystems. [For more recent details see section A.6.17 and page 84 in particular.]

Annual trends toward earlier spring melt and reduced snowpack are already affecting water resources in the western United States and these trends are expected to continue. Under higher [greenhouse gas emission] scenarios, and assuming no change to current water resources management, chronic, long-duration hydrological drought is increasingly possible before the end of this century.

The magnitude of climate change beyond the next few decades will depend primarily on the amount of greenhouse gases (especially carbon dioxide) emitted globally. Without major reductions in emissions, the increase in annual average global temperature relative to preindustrial times could reach 9°F (5°C) or more by the end of this century. With significant reductions in emissions, the increase in annual average global temperature could be limited to 3.6°F (2°C) or less. [For further details see section A.6.6 on page 68.]

The global atmospheric carbon dioxide (CO₂) concentration has now passed 400 parts per million (ppm), a level that last occurred about 3 million years ago, when both global average temperature and sea
level were significantly higher than today. [Fig. 18 illustrates the meaning of “significantly higher.”] Continued growth in CO₂ emissions over this century and beyond would lead to an atmospheric concentration not experienced in tens to hundreds of millions of years. There is broad consensus that the further and the faster the Earth system is pushed towards warming, the greater the risk of unanticipated changes and impacts, some of which are potentially large and irreversible. [The problem with natural gas as a bridge fuel is exactly that is speeds up the change of the climate system, risking the point of no return. For more about the risk of methane and its misrepresentation see section A.9]

The observed increase in carbon emissions over the past 15–20 years has been consistent with higher emissions pathways. In 2014 and 2015, emission growth rates slowed as economic growth became less carbon-intensive. Even if this slowing trend continues, however, it is not yet at a rate that would limit global average temperature change to well below 3.6°F (2°C) above preindustrial levels.

A.6.5  Fourth National Climate Assessment chapter 1: our globally changing climate

A.6.5.1 Key finding 1: changes are fast & unambiguous

The global climate continues to change rapidly compared to the pace of the natural variations in climate that have occurred throughout Earth’s history. Trends in globally averaged temperature, sea level rise, upper-ocean heat content, land-based ice melt, arctic sea ice, depth of seasonal permafrost thaw, and other climate variables provide consistent evidence of a warming planet. These observed trends are robust and have been confirmed by multiple independent research groups around the world. (Very high confidence)

A.6.5.2 Key finding 2: extreme weather events increasing in frequency

The frequency and intensity of extreme heat and heavy precipitation events are increasing in most continental regions of the world (very high confidence). These trends are consistent with expected physical responses to a warming climate. Climate model studies are also consistent with these trends, although models tend to underestimate the observed trends, especially for the increase in extreme precipitation events (very high confidence for temperature, high confidence for extreme precipitation). The frequency and intensity of extreme high temperature events are virtually certain to increase in the future as global temperature increases (high confidence). Extreme precipitation events will very likely continue to increase in frequency and intensity throughout most of the world (high confidence). Observed and projected trends for some other types of extreme events, such as floods, droughts, and severe storms, have more variable regional characteristics.

A.6.5.3 Key finding 3: climate change is human-caused

Many lines of evidence demonstrate that it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. Formal detection and attribution studies for the period 1951 to 2010 find that the observed global mean surface temperature warming lies in the middle of the range of likely human contributions to warming over that same period. We find no convincing evidence that natural variability can account for the amount of global warming observed over the industrial era. For the period extending

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268Wuebbles et al., “Our globally changing climate,” supra note 82.
over the last century, there are no convincing alternative explanations supported by the extent of the observational evidence. Solar output changes and internal variability can only contribute marginally to the observed changes in climate over the last century, and we find no convincing evidence for natural cycles in the observational record that could explain the observed changes in climate. (Very high confidence)

A.6.5.4 Key finding 4: without drastic cuts in emissions temperature could increase by 9°F (5°C)  Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades will depend primarily on the amount of greenhouse (heat-trapping) gases emitted globally and on the remaining uncertainty in the sensitivity of Earth’s climate to those emissions (very high confidence). With significant reductions in the emissions of greenhouse gases, the global annually averaged temperature rise could be limited to 3.6°F (2°C) or less. Without major reductions in these emissions, the increase in annual average global temperatures relative to preindustrial times could reach 9°F (5°C) or more by the end of this century (high confidence).

A.6.5.5 Key finding 5: locally natural climate variation is amplified  Natural variability, including El Niño events and other recurring patterns of ocean–atmosphere interactions, impact temperature and precipitation, especially regionally, over months to years. The global influence of natural variability, however, is limited to a small fraction of observed climate trends over decades. (Very high confidence)

A.6.5.6 Key finding 6: average temperature increases over last decades are fast]  Longer-term climate records over past centuries and millennia indicate that average temperatures in recent decades over much of the world have been much higher, and have risen faster during this time period, than at any time in the past 1,700 years or more, the time period for which the global distribution of surface temperatures can be reconstructed. (High confidence) [section A.6.25 contains specifics pertaining to the rate of change over the last 420,000 years and the inability of organisms and ecosystems to adapt to rates of change in global temperature and atmospheric CO₂ that over the past century are 2 to 3 orders of magnitude higher than most of the changes that have occurred over the past 420,000 years.]

A.6.6 Global warming—additional details

A.6.6.1 Temperature change  One of the crucial observables is the average global surface temperature. As science predicted, this quantity tracks the greenhouse gas emissions due to human activities: the temperature shows the same “compound interest” increase on top of the pre-1750 offset. The 1990 Environmental Protection Agency report to Congress also mentions that the greenhouse effect would continue to intensify for more than a century after stabilization, and that without policies in place to limit greenhouse gas emissions the earth might be committed to a global warming of 2–4°C (3–7°F) by 2025 and 3–6°C (4–10°F) by 2050. ²⁶⁹,²⁷⁰,²⁷¹,²⁷²

²⁶⁹Lashof and Tirpak, supra note 207, p. 1.
²⁷¹Hansen et al., “Assessing ‘dangerous climate change’: required reduction of carbon emissions to protect young people, future generations and nature,” supra note 9, p. 3.
²⁷²Conclusion (2) “that the accumulation of greenhouse gases in our atmosphere is exerting a warming effect on the global climate;” EPA’s Denial of the Petitions To Reconsider the Endangerment and Cause...
The temperature increase in the U.S. varies considerably across the continent—see Fig. 14—but global warming and its impact vary much more strongly globally than is visible on the scale of the U.S.

Figure 14: *Observed U.S. temperature change*: the colors on the map of the contiguous U.S., Hawaii, and Alaska show temperature changes over 22 years (1991–2012) compared to the 1901–1960 average. The bar graph on the right shows the average temperature changes for the U.S. by decade for 1901–2012. The bar graph (2000s decade) includes 2011 and 2012. Already, the period from 2001 to 2012 was warmer than any previous decade in every region, a trend that continues today. (Figure source: NOAA NCDC / CICS-NC).

Even within the U.S., large local variations already occur. Alaska is a case in point: “Alaskans have experienced some of the largest increases in temperature between 1970 and the present.”

As the *Fourth National Climate Assessment* mentions, referring to polar amplification:

Statistically significant warming is projected for all parts of the United States throughout the century .... Consistent with polar amplification, warming rates (and spatial gradients) are greater at higher latitudes. For example, warming is largest in Alaska (more than 12.0°F [6.7°C] in the northern half of the state by late-century under RCP8.5, driven in part by a decrease in snow cover and thus surface albedo [a measure of light reflectivity]. Similarly, northern regions

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273 Melillo, Richmond, and Yohe, *supra* note 77.
277 Wayne, *supra* note 176.
of the contiguous United States have slightly more warming than other regions (roughly 9.0°F [5.5°C] in the Northeast, Midwest, and Northern Great Plains by late-century under RCP8.5 ...)

A.6.6.2 Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report: global temperature increases As should be evident by now, one crucial, observable change is the rapid increase in recorded global surface temperatures. As a result of increased atmospheric greenhouse gases due to human activities, and as implied by the laws of physics that govern the interaction of (sun) light and matter, the earth has been warming as science predicted. The increased concentrations of greenhouse gases in our atmosphere, primarily CO₂, have raised global surface temperature by 0.9°C (1.5°F) from 1880 to 2015, which is close to, and probably slightly above, the maximum temperature of the Holocene era, the period of relatively stable climate over the last 10,000 years, during which human civilization developed; see Fig. 12. Over the last century, the earth has warmed at a rate “roughly ten times faster than the average rate of ice-age- recovery warming.” It takes decades to centuries it takes for the climate system to respond to changes in atmospheric CO₂ composition, due to the large thermal inertia (heat capacity) of the oceans. As a consequence, there is substantial additional warming already “in the pipeline,” which is “difficult if not impossible to avoid.”

Intergovernmental Panel on Climate Change (IPCC) concluded that:

It is certain that global mean surface temperature (GMST) has increased since the late 19th century (Figures TS.1 and TS.2). Each of the past three decades has been successively warmer at the Earth’s surface than any the previous decades in the instrumental record, and the decade of the 2000’s has been the warmest.

Figure TS.1 is reproduced here as Fig. 15.
We note in this context that, as the National Oceanic and Atmospheric Administration (NOAA) reported on January 18, 2018:\textsuperscript{284}

After three consecutive years of record-high temperatures for the globe, Earth was a slightly cooler planet in 2017. But not by much.

Yearly and decadal oscillations are part of the climate system even in the absence of human activity. Separating these oscillations from the consequences of our impact on the climate is a problem that can be dealt with by averaging time series over longer periods. This filters out the year-to-year variations, \textit{e.g.}, in temperature, and brings out decadal trends.\textsuperscript{285} It turns out that on a decadal scale, the surface of the planet has warmed at a rate of roughly 0.12°C per decade since 1951.\textsuperscript{286} Note that using this result for future projections is likely

\begin{footnotesize}
\begin{itemize}
  \item \textsuperscript{284} NOAA: 2017 was 3rd warmest year on record for the globe. National Oceanic and Atmospheric Administration (NOAA). Jan. 18, 2018. URL: \url{http://www.noaa.gov/news/noaa-2017-was-3rd-warmest-year-on-record-for-globe} (visited on May 16, 2018).
  \item \textsuperscript{285} One often uses eleven-year moving averages to filter out sunspot activity.
  \item \textsuperscript{286} section TS.2.2, Stocker \textit{et al.}, “Technical Summary,” \textit{supra} note 279, p. 37.
\end{itemize}
\end{footnotesize}
produce an underestimate, because it ignores the accelerating rate of change.

Indeed, all curves in Fig. 15 show clear, but hard to quantify curvature, i.e., an accelerating trend. The issue is: 287

**Nonlinear Trends**

There is no a priori physical reason why the long-term trend in climate variables should be linear in time. Climatic time series often have trends for which a straight line is not a good approximation . . . When linear trends for two parts of a longer time series are calculated separately, the trends calculated for two shorter periods may be very different (even in sign) from the trend in the full period, if the time series exhibits significant nonlinear behavior in time . . . .

On the contrary, there is an excellent, a priori physical reason to expect nonlinear behavior: as mentioned before on page 17, an exponentially driven system, such as the climate system—see Fig. 8—tends to respond exponentially, at least until some form of saturation sets in.

As was discussed in section A.3, and is particularly clear from Figs. 7 through 9, straight-line fits result in systematically underestimated projections, as discussed further in section A.11, page 138.

A.6.7  *Fourth National Climate Assessment* chapter 2: physical drivers of climate change

A.6.7.1  **Key finding 1: earth’s energy imbalance is mainly anthropogenic** 288

Human activities continue to significantly affect Earth’s climate by altering factors that change its radiative balance. These factors, known as radiative forcings, include changes in greenhouse gases, small airborne particles (aerosols), and the reflectivity of the earth’s surface. In the industrial era, human activities have been, and are increasingly, the dominant cause of climate warming. The increase in radiative forcing due to these activities has far exceeded the relatively small net increase due to natural factors, which include changes in energy from the sun and the cooling effect of volcanic eruptions.  

A.6.7.2  **Key finding 2: the role of aerosols**  

Aerosols due to Human Activity Play a Profound and Complex Role in the Climate System through radiative effects in the atmosphere and on snow and ice surfaces and through effects on cloud formation and properties. The combined forcing of aerosol–radiation and aerosol–cloud interactions is negative (cooling) over the industrial era (high confidence), offsetting a substantial part of greenhouse gas forcing, which is currently the predominant human contribution. The magnitude of this offset, globally averaged, has declined in recent decades, despite increasing trends in aerosol emissions or abundances in some regions (medium to high confidence).

A.6.7.3  **Key finding 3: feedbacks generally accelerate global warming**  

The interconnected Earth–atmosphere–ocean system includes a number of positive and negative feedback processes that can either strengthen (positive feedback) or weaken (negative feedback) the system’s responses to human and natural influences. These feedbacks operate on

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a range of timescales from very short (essentially instantaneous) to very long (centuries). Global warming by net radiative forcing over the industrial era includes a substantial amplification from these feedbacks (approximately a factor of three) \( (high\ confidence) \). While there are large uncertainties associated with some of these feedbacks, the net feedback effect over the industrial era has been positive (amplifying warming) and will continue to be positive in coming decades \( (very\ high\ confidence) \).

A.6.8 Fourth National Climate Assessment chapter 3: detection and attribution of climate change

A.6.8.1 Key finding 1: global warming attributed to human activity\(^{289}\) The likely range of the human contribution to the global mean temperature increase over the period 1951–2010 is 1.1 °C to 1.4 °F \( (0.6 \text{ °C to } 0.8 \text{ °F}) \), and the central estimate of the observed warming of 1.2 °F \( (0.65 \text{ °F}) \) lies within this range \( (high\ confidence) \). This translates to a likely human contribution of 93%–123% of the observed 1951–2010 change. It is extremely likely that more than half of the global mean temperature increase since 1951 was caused by human influence on climate \( (high\ confidence) \). The likely contributions of natural forcing and internal variability to global temperature change over that period are minor \( (high\ confidence) \).

A.6.8.2 Key finding 2: event attribution, a rapidly advancing science The science of event attribution is rapidly advancing through improved understanding of the mechanisms that produce extreme events and the marked progress in development of methods that are used for event attribution \( (high\ confidence) \).

A.6.9 Fourth National Climate Assessment chapter 4: climate models, scenarios, and projections

A.6.9.1 Key finding 1: future warming “baked’ in”\(^{290}\) If greenhouse gas concentrations were stabilized at their current level, existing concentrations would commit the world to at least an additional 1.1°F \( (0.6 \text{ °C}) \) of warming over this century relative to the last few decades \( (high\ confidence\ in\ continued\ warming,\ medium\ confidence\ in\ amount\ of\ warming) \). [For more specifics see section A.6.10, page 74.]

A.6.9.2 Key finding 2: projected temperature increase over the next two decades Over the next two decades, global temperature increase is projected to be between 0.5°F and 1.3°F \( (0.3 \text{ °C to } 0.7 \text{ °C}) \) \( (medium\ confidence) \). This range is primarily due to uncertainties in natural sources of variability that affect short-term trends. In some regions, this means that the trend may not be distinguishable from natural variability \( (high\ confidence) \). [This is related to humanity’s resolve to act decisively; see section A.10, page 133.]

A.6.9.3 Key finding 3: projected temperature increase beyond two decades Beyond the next few decades, the magnitude of climate change depends primarily on cumulative emissions of greenhouse gases and aerosols and the sensitivity of the climate system


to those emissions *(high confidence)*. Projected changes range from 4.7°–8.6°F (2.6°–4.8°C) under the higher [greenhouse gas emission] scenario (RCP8.5) [*RCP stands for Representative Concentration Pathway*]**291** to 0.5°–1.3°F (0.3°–1.7°C) under the much lower scenario (RCP2.6), for 2081–2100 relative to 1986–2005 *(medium confidence)*.

### A.6.9.4 Key finding 4: current atmospheric CO₂ levels from a geological timescale perspective

Global mean atmospheric carbon dioxide (CO₂) concentration has now *passed* 400 ppm, a level that last occurred about 3 million years ago, when global average temperature and sea level were significantly higher than today *(emphasis added)* *(high confidence)*. Continued growth in CO₂ emissions over this century and beyond would lead to an atmospheric concentration not experienced in tens of millions of years *(medium confidence)*. The present-day emissions rate of nearly 10 GtC per year suggests that *there is no climate analog for this century any time in at least the last 50 million years* *(emphasis added)* *(medium confidence)*.

### A.6.9.5 Key finding 5: 2014–2015 greenhouse gas emissions

The observed increase in global carbon emissions over the past 15–20 years has been consistent with higher [greenhouse gas emission] scenarios *(very high confidence)*. In 2014 and 2015, emission growth rates slowed as economic growth has become less carbon-intensive *(medium confidence)*. Even if this trend continues, however, it is not yet at a rate that would limit the increase in the global average temperature to well below 3.6°F (2°C) above preindustrial levels *(high confidence)*. *(Note that the phrase “emission rates slowed” is meaningless unless one explicitly defines how the carbon dioxide equivalent of the emissions is calculated. Typically, this is done in a way that vastly underestimating the effect of natural gas. See the Technical Appendix, page 150.)*

### A.6.9.6 Key finding 6: predicting future human behavior: science or speculation?

Combining output from global climate models and dynamical and statistical downscaling models using advanced averaging, weighting, and pattern scaling approaches can result in more relevant and robust future projections. For some regions, sectors, and impacts, these techniques are increasing the ability of the scientific community to provide guidance on the use of climate projections for quantifying regional-scale changes and impacts *(medium to high confidence)*.

### A.6.10 “Baked-In” warming—additional details

In addition to the information presented in section A.6.6, we note the following:

1. *Less than 2°C warming by 2100 unlikely.* **292**

The likely range of global temperature increase is 2.0–4.9°C, with median 3.2°C and a 5% (1%) chance that it will be less than 2°C (1.5°C). Population growth is not a major contributing factor. Our model is not a ‘business as

**291**Wayne, supra note 176, “RCPs are referred to as pathways in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. In addition, the term pathway is meant to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as a stabilization level, that is of interest, but also the trajectory that is taken over time to reach that outcome.” Postfixes are used to distinguish the various pathways.

usual’ scenario, but rather is based on data which already show the effect of emission mitigation policies. Achieving the goal of less than 1.5°C warming will require carbon intensity to decline much faster than in the recent past.

2. *Two degrees of warming already “baked in.”*293,294

Even if humans could instantly turn off all our emissions of greenhouse gases, the Earth would continue to heat up about two more degrees Fahrenheit by the turn of the century, according to a sophisticated new analysis.

3. *Greater future global warming inferred from earth’s recent energy budget.*295

Our results suggest that achieving any given global temperature stabilization target will require steeper greenhouse gas emissions reductions than previously calculated.

A.6.11 *Fourth National Climate Assessment* chapter 5: large-scale circulation and climate variability

A.6.11.1 Key finding 1: expansion of the tropics296 The tropics have expanded poleward by about 70 to 200 miles in each hemisphere over the period 1979–2009, with an accompanying shift of the subtropical dry zones, midlatitude jets, and storm tracks (*medium to high confidence*). Human activities have played a role in this change (*medium confidence*), although confidence is presently low regarding the magnitude of the human contribution relative to natural variability.

A.6.11.2 Key finding 2: impact of human activities on recurring climate patterns Recurring patterns of variability in large-scale atmospheric circulation (such as the North Atlantic Oscillation and Northern Annular Mode) and the atmosphere–ocean system (such as El Niño–Southern Oscillation) cause year-to-year variations in U.S. temperatures and precipitation (*high confidence*). Changes in the occurrence of these patterns or their properties have contributed to recent U.S. temperature and precipitation trends (*medium confidence*), although confidence is low regarding the size of the role of human activities in these changes.

[An example of such a pattern change has been observed in a study based “on an annually resolved coralline algal [a reddish seaweed with a chalky stem] time series from the northwest Atlantic Ocean that exhibits multidecadal variability extending back six centuries.”297]
A.6.12 Fourth National Climate Assessment chapter 6: temperature changes in the United States

A.6.12.1 Key finding 1: United States warming
Annual average temperature over the contiguous United States has increased by 1.2°F (0.7°C) for the period 1986–2016 relative to 1901–1960 and by 1.8°F (1.0°C) based on a linear regression and the for the period 1895–2016 (very high confidence). Surface and satellite data are consistent in their depiction of rapid warming since 1979 (high confidence). Paleo-temperature evidence shows that recent decades are the warmest of the past 1,500 years (medium confidence). [See more on the questionable use of linear regression in section A.11, page 138.]

A.6.12.2 Key finding 2: frequency temperature extremes in United States
There have been marked changes in temperature extremes across the contiguous United States. The frequency of cold waves has decreased since the early 1900s, and the frequency of heat waves has increased since the mid-1960s. The Dust Bowl era of the 1930s remains the peak period for extreme heat. The number of high temperature records set in the past two decades far exceeds the number of low temperature records. (Very high confidence) [Note that a decrease in frequency of cold waves is not inconsistent with a simultaneous increase in the magnitude of their extremes—see page 62.]

A.6.12.3 Key finding 3: projected temperature increase in United States
Annual average temperature over the contiguous United States is projected to rise (very high confidence). Increases of about 2.5°F (1.4°C) are projected for the period 2021–2050 relative to 1976–2005 in all RCP [Representative Concentration Pathway] scenarios, implying recent record-setting years may be “common” in the next few decades (high confidence). Much larger rises are projected by late century (2071–2100): 2.8°–7.3°F (1.6°–4.1°C) in a lower [greenhouse gas emission] scenario (RCP4.5) and 5.8°–11.9°F (3.2°–6.6°C) in the higher scenario (RCP8.5) (high confidence).

A.6.12.4 Key finding 4: extreme temperatures will increase more than average
Extreme temperatures in the contiguous United States are projected to increase even more than average temperatures. The temperatures of extremely cold days and extremely warm days are both expected to increase. Cold waves are projected to become less intense while heat waves will become more intense. The number of days below freezing is projected to decline while the number above 90°F will rise. (Very high confidence) [As noted on page 66 Hansen and Sato showed convincingly that this is already happening.]

298Vose et al., supra note 276.
299The term linear regression is ambiguous. It may mean that the relationship between the dependent and explanatory variables is linear. Examples are the curves in Figs. 9 and 25. In both of the latter the explanatory variable is the exponential obtained from the regression that produced the curve in Fig. 8 in which the time constant is a non-linear parameter. Alternatively, linear regression may be used to indicate that the explanatory variables themselves are linear functions.
300outpacing projections
301Wayne, supra note 176.
302Hansen and Sato, supra note 94.
A.6.13 Heat waves—additional details

Deadly heat waves are projected in the densely populated agricultural regions of South Asia. The most intense hazard from extreme future heat waves is concentrated around densely populated agricultural regions of the Ganges and Indus river basins. Climate change, without mitigation, presents a serious and unique risk in South Asia, a region inhabited by about one-fifth of the global human population, due to an unprecedented combination of severe natural hazard and acute vulnerability.

A.6.14 Fourth National Climate Assessment chapter 7: precipitation change in the United States

A.6.14.1 Key finding 1: increase in national average precipitation—decrease in some areas. Annual precipitation has decreased in much of the West, Southwest, and Southeast and increased in most of the Northern and Southern Plains, Midwest, and Northeast. A national average increase of 4% in annual precipitation since 1901 is mostly a result of large increases in the fall season. (Medium confidence)

A.6.14.2 Key finding 2: more extreme precipitation events observed. Heavy precipitation events in most parts of the United States have increased in both intensity and frequency since 1901 (high confidence). There are important regional differences in trends, with the largest increases occurring in the northeastern United States (high confidence). In particular, mesoscale convective systems (organized clusters of thunderstorms)—the main mechanism for warm season precipitation in the central part of the United States—have increased in occurrence and precipitation amounts since 1979 (medium confidence).

A.6.14.3 Key finding 3: projected increase in extreme precipitation events. The frequency and intensity of heavy precipitation events are projected to continue to increase over the 21st century (high confidence). Mesoscale convective systems in the central United States are expected to continue to increase in number and intensity in the future (medium confidence). There are, however, important regional and seasonal differences in projected changes in total precipitation: the northern United States, including Alaska, is projected to receive more precipitation in the winter and spring, and parts of the southwestern United States are projected to receive less precipitation in the winter and spring (medium confidence).

A.6.14.4 Key finding 4: extreme snowfall increase in some parts of United States and decrease in others. Northern Hemisphere spring snow cover extent, North America maximum snow depth, snow water equivalent in the western United States, and extreme snowfall years in the southern and western United States have all declined, while

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extreme snowfall years in parts of the northern United States have increased \((medium\ confidence)\). Projections indicate large declines in snowpack in the western United States and shifts to more precipitation falling as rain than snow in the cold season in many parts of the central and eastern United States \((high\ confidence)\).

A.6.15 Fourth National Climate Assessment chapter 8: droughts, floods, and wildfire

A.6.15.1 Key finding 1: record droughts and heat waves in parts of United States

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 \((very\ high\ confidence)\). While by some measures drought has decreased over much of the continental United States in association with long-term increases in precipitation, neither the precipitation increases nor inferred drought decreases have been confidently attributed to anthropogenic forcing.

A.6.15.2 Key finding 2: surface soil has less moisture because of increased temperatures

The human effect on recent major U.S. droughts is complicated. Little evidence is found for a human influence on observed precipitation deficits, but much evidence is found for a human influence on surface soil moisture deficits due to increased evapotranspiration caused by higher temperatures. \((High\ confidence)\)

A.6.15.3 Key finding 3: further decrease top soil moisture expected

Future decreases in surface \((top\ 10\ cm)\) soil moisture from anthropogenic forcing over most of the United States are likely as the climate warms under higher [greenhouse gas emission] scenarios. \((Medium\ confidence)\)

A.6.15.4 Key finding 4: big snowpack reductions expected

Substantial reductions in western U.S. winter and spring snowpack are projected as the climate warms. Earlier spring melt and reduced snow water equivalent have been formally attributed to human-induced warming \((high\ confidence)\) and will very likely be exacerbated as the climate continues to warm \((very\ high\ confidence)\). Under higher [greenhouse gas emission] scenarios, and assuming no change to current water resources management, chronic, long-duration hydrological drought is increasingly possible by the end of this century \((very\ high\ confidence)\).

A.6.15.5 Key finding 5: flood statistics develop non-uniformly across United States

Detectable changes in some classes of flood frequency have occurred in parts of the United States and are a mix of increases and decreases. Extreme precipitation, one of the controlling factors in flood statistics, is observed to have generally increased and is projected to continue to do so across the United States in a warming atmosphere. However, formal attribution approaches have not established a significant connection of increased riverine flooding to human-induced climate change, and the timing of any emergence of a future detectable anthropogenic change in flooding is unclear. \((Medium\ confidence)\)

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A.6.15.6 Key finding 6: increase of large forest fires projected to continue
The incidence of large forest fires in the western United States and Alaska has increased
since the early 1980s (high confidence) and is projected to further increase in those regions
as the climate warms, with profound changes to certain ecosystems (medium confidence).
[We revisit these topics in section A.6.17, page 80.]

A.6.16 Fourth National Climate Assessment chapter 9: extreme storms

A.6.16.1 Key finding 1: more North Atlantic hurricanes because of human
activities
Human activities have contributed substantially to observed ocean–atmosphere
variability in the Atlantic Ocean (medium confidence), and these changes have contributed
to the observed upward trend in North Atlantic hurricane activity since the 1970s (medium
confidence).

A.6.16.2 Key finding 2: projected increase in frequency and intensity of hur-
ricanes, tropical cyclones
Both theory and numerical modeling simulations generally
indicate an increase in tropical cyclone (TC) intensity in a warmer world, and the models
generally show an increase in the number of very intense TCs. For Atlantic and eastern
North Pacific hurricanes and western North Pacific typhoons, increases are projected in pre-
cipitation rates (high confidence) and intensity (medium confidence). The frequency of the
most intense of these storms is projected to increase in the Atlantic and western North Pacific
(low confidence) and in the eastern North Pacific (medium confidence). [Also see page 81.]

A.6.16.3 Key finding 3: likely increase in severe thunderstorms, tornadoes,
and winter storms
Tornado activity in the United States has become more variable,
particularly over the 2000s, with a decrease in the number of days per year with tornadoes
and an increase in the number of tornadoes on these days (medium confidence). Confidence
in past trends for hail and severe thunderstorm winds, however, is low. Climate models
consistently project environmental changes that would putatively support an increase in the
frequency and intensity of severe thunderstorms (a category that combines tornadoes, hail,
and winds), especially over regions that are currently prone to these hazards, but confidence
in the details of this projected increase is low.

A.6.16.4 Key finding 4: locally varying changes in snowstorm frequency and
intensity
There has been a trend toward earlier snowmelt and a decrease in snowstorm frequency
on the southern margins of climatologically snowy areas (medium confidence). Winter
storm tracks have shifted northward since 1950 over the Northern Hemisphere (medium con-
fidence). Projections of winter storm frequency and intensity over the United States vary
from increasing to decreasing depending on region, but model agreement is poor and confi-
dence is low. Potential linkages between the frequency and intensity of severe winter storms
in the United States and accelerated warming in the Arctic have been postulated, but they
are complex, and, to some extent contested, and confidence in the connection is currently
low.

A.6.16.5 Key finding 5: increase in localized variations of atmospheric humidity
and flooding events
The frequency and severity of landfalling “atmospheric rivers” on

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the U.S. West Coast (narrow streams of moisture that account for 30%–40% of the typical snowpack and annual precipitation in the region and are associated with severe flooding events) will increase as a result of increasing evaporation and resulting higher atmospheric water vapor that occurs with increasing temperature. (Medium confidence)

A.6.17 Precipitation, storms, wildfires, and drought—additional details

As predicted, precipitation patterns have changed due to increases in atmospheric moisture levels and changes in atmospheric air circulation patterns, another indicator that the earth is warming.\footnote{TO BE CHECKED Melillo, Richmond, and Yohe, supra note 77, pp. 1, 27, 32, 36.} As the earth warms, moisture levels increase because warmer air at atmospheric pressure holds more moisture than colder air. In particular in more arid regions, as a consequence, higher temperatures lead to greater evaporation. This combination of climate change effects has serious consequences for U.S. water resources.\footnote{See section 11, Water Resources. In: supra note 44, p. 110.}

These changes in the earth’s water cycle increase the potential for, and severity of severe storms, flooding, and droughts.\footnote{Id., p. 111.} Storm-prone areas experience a greater chance of severe storms and this heightened threat will continue.\footnote{Id., pp. 120-121.} In arid regions, increased precipitation is likely to cause flash flooding followed by drought.\footnote{Melillo, Richmond, and Yohe, supra note 77, p. 43.}

These changes are already occurring. Droughts in parts of the midwestern, southeastern, and western United States have increased in frequency and severity within the last fifty years and concomitant with rising temperatures.\footnote{Melillo, Richmond, and Yohe, supra note 77, p. 43.} Most of the recent heat waves can be attributed to human-caused climate disruption.\footnote{Id., p. 148.} For example, in September 2015 almost 20% of the United States was experiencing a severe to exceptional drought while over 50% of the United States was abnormally dry. The western United States, over 40% was experiencing a severe to exceptional drought and 92% of California was experiencing a severe to exceptional drought. Nearly 60 million people in the west were being affected by drought. Despite a 2015–2016 winter that had been wetter than the previous year, 2016 started off dryer than normal, with significant implications for agriculture, rivers, fish, and drinking water supplies during the subsequent summer and fall. As of March 2016, one-third of the continental United States was abnormally dry, while two-thirds of the west was abnormally dry.\footnote{"The summer 2011 heat wave and drought in Texas was primarily driven by precipitation deficits, but the human contribution to climate change approximately doubles the probability that the heat was record-breaking.”} Melillo, Richmond, and Yohe, supra note 77, p. 38.

Fig. 16 shows the conditions of exceptional drought that prevailed in California from 2013 until 2017.\footnote{United States Drought Monitor: Time Series. The National Drought Mitigation Center. URL: http://droughtmonitor.unl.edu/Data/TimeSeries.aspx (visited on Dec. 2, 2017).} \footnote{Id.}

\footnote{Definitions of the drought classification can be found here: Drought Classification. USD. URL: http://droughtmonitor.unl.edu/AboutUSDM/DroughtClassification.aspx (visited on Dec. 22, 2017).}
The laws of physics and the past climate record imply that extreme precipitation events will increase globally, particularly in tropical and high latitude regions, while decreasing in subtropical and mid-latitude regions, with longer periods between normal heavy rainfalls.\textsuperscript{318,319} Climate change is already causing, and will continue to result in more frequent, extreme and costly weather events, such as hurricanes.\textsuperscript{320} The annual number of major tropical storms and hurricanes has increased over the past 100 years in North America, fueled by the increasing temperatures in the Atlantic sea surface. Indeed, as the 2017, \textit{Fourth National Climate Assessment} mentions:\textsuperscript{321}

Both physics and numerical modeling simulations generally indicate an increase in tropical cyclone intensity in a warmer world, and the models generally show an increase in the number of very intense tropical cyclones.

Hence it should not come as a surprise that the 2017 hurricane season was the most expensive in U.S. history with a series of major storms, including Harvey, Maria, and Irma have caused unprecedented damage.\textsuperscript{322} Indeed, a recent study finds that “Harvey could not have produced so much rain without human-induced climate change.” \textsuperscript{323} Recent research\textsuperscript{324} cites the unprecedented rainfall totals associated with the ‘stall’ of hurricane Harvey over Texas in 2017 as a notable example of the relationship between regional rainfall amounts and the reduced speed at which such weather systems move because of climate change.

\textsuperscript{318} supra note 44, pp. ES-4, 74–77, 97, and 100–101.

\textsuperscript{319}Chapter 7 of Wuebbles et al., \textit{Climate Science Special Report: Fourth National Climate Assessment, Volume I}, supra note 78.

\textsuperscript{320}Melillo, Richmond, and Yohe, \textit{supra} note 77, p. 38.

\textsuperscript{321}Wuebbles et al., \textit{Climate Science Special Report: Fourth National Climate Assessment, Volume I}, supra note 78, p. 22.


September 4, 2018, p. 81
As the National Oceanic and Atmospheric Administration (NOAA) reports and as Fig. 17 shows:\footnote{325}

During 2017, the U.S. experienced a historic year of weather and climate disasters. In total, the U.S. was impacted by 16 separate billion-dollar disaster events tying 2011 for the record number of billion-dollar disasters for an entire calendar year.

Figure 17: In 2017, there were 16 weather and climate disaster events with losses exceeding $1 billion each across the United States. These events included one drought event, two flooding events, one freeze event, eight severe storm events, three tropical cyclone events, and one wildfire event [National Oceanic and Atmospheric Administration (NOAA), National Centers for Climate Information].

Other changes consistent with climate modeling and due to global warming have been observed not just in the amount, intensity, and frequency of precipitation but also in the type of precipitation.\footnote{326} In higher altitude regions and in mountainous areas, more precipitation is falling as rain rather than as snow.\footnote{327} With early snow melt occurring because of climate change, the reduction in snowpack can aggravate water supply problems.\footnote{328}

The World Meteorological Organization in its report on 2016 states:\footnote{329}
Northern hemisphere mean annual snow-cover extent for 2016 was 24.6 million km$^2$, 0.5 million km$^2$ below the 1967–2015 average and the 12th lowest value on record. This was very similar to 2015.

After above-average snow cover in January, snow cover was well below average from February to June, with cover between 2.4 million km$^2$ and 3.3 million km$^2$ below average. *The April mean snow-cover extent was the lowest on record, with March ranking second, February and June third and May fourth* [emphasis added].

The report on 2017 of the same organization mentions that:

> The overall risk of heat-related illness or death has climbed steadily since 1980, with around 30% of the world’s population now living in climatic conditions that deliver deadly temperatures at least 20 days a year.

As the *Fourth National Climate Assessment* sums it up in its 2017 report:

> In addition to warming, many other aspects of global climate are changing, primarily in response to human activities. **Thousands of studies conducted by researchers around the world have documented changes in surface, atmospheric, and oceanic temperatures; melting glaciers; diminishing snow cover; shrinking sea ice; rising sea levels; ocean acidification; and increasing atmospheric water vapor.**

The 2010 summer heat wave in western Russia “was extraordinary, with the region experiencing the warmest July since at least 1880 and numerous locations setting all-time maximum temperature records.”

As is well-known, heat can destroy crops, trigger wildfires, exacerbate air pollution, and cause increased illness and deaths. Similar impacts are occurring across the United States:

> Ecosystems and their services (land and water resources, agriculture, biodiversity) experience a wide range of stresses, including pests and pathogens, invasive species, air pollution, extreme events, wildfires and floods.

Climate change and ocean acidification are threatening the survival and well-being of millions of species of plants, fish and wildlife, and earth’s biodiversity. As many as one in six species are threatened with extinction due to climate change. Many more species that do not face extinction will face changes in abundance, distributions, and interactions between species that cause adverse impacts for ecosystems and humans.

This is how Urban, who performed a meta-analysis of 131 published predictions, sums up his conclusion:

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335 Id.
In 1981, Hansen and colleagues predicted that the signal of global climate change would soon emerge from the stochastic noise [random changes obscuring trends] of weather . . . . Thirty years later, we are reaching a similar threshold for the effects of climate change on biodiversity. Extinction risks from climate change are expected not only to increase but to accelerate for every degree rise in global temperatures. The signal of climate change—induced extinctions—will become increasingly apparent if we do not act now to limit future climate change.

Climate change with its higher temperatures and droughts are leading to longer and more destructive wildfire seasons. In 2015 for example, Alaska had its second worst wildfire season in history with over five million acres burned as of August. As the 2017 wildfire season in California and the subsequent mudslides in January of 2018 illustrate with a vengeance, wildfire seasons are becoming increasingly destructive, dangerous, and expensive as a result. Indeed, as the Fourth National Climate Assessment sums it up: “Recent decades have seen a profound increase in forest fire activity over the western United States and Alaska.”

The title of this paper speaks for itself: *Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years.*

CAL FIRE on Monday, October 30, 2017 issued a press release summarizing the damage of the 2017 season:

Since the start of the October Fire Siege on Sunday, October 8, CAL FIRE responded to 250 new wildfires. At the peak of the wildfires there were 21 major wildfires that, in total, burned over 245,000 acres, 11,000 firefighters battled the destructive fires that at one time forced 100,000 to evacuate, destroyed an estimated 8,900 structures (as damage assessment continues, this is the latest count), and sadly, took the lives of 43 people.

This was after a previous press release in which CAL FIRE stated that: “After one of the deadliest and most destructive weeks in California’s history, firefighters are preparing for another significant wind event in Southern California.”

As the 2017 *Fourth National Climate Assessment* notes, there is a serious danger of mutual reinforcement of extreme events.

The physical and socioeconomic impacts of compound extreme events (such as simultaneous heat and drought, wildfires associated with hot and dry conditions, or flooding associated with high precipitation on top of snow or waterlogged ground) can be greater than the sum of the parts (*very high confidence*). Few analyses consider the spatial or temporal correlation between extreme events.

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That few studies address such mutual reinforcement (aka superadditivity) of extreme events has a simple explanation: we are talking literally about coincidences. This, by its very nature, limits availability of data.

To sum up we mention that the U.S. National Interagency Fire Center\textsuperscript{342} reports on Federal Firefighting Costs. As we show on page 86, the last four reported years (2012–2016) of the 22 listed happened during the last five years. The costs increases are sufficiently big it is reasonable to ignore inflation, which shows that the probability of this happening purely by chance is about one in 10,000.

The Department of Interior agencies include: Bureau of Indian Affairs, Bureau of Land Management; National Park Service; and U.S. Fish and Wildlife Service.

- The U.S. Forest Service is an agency of the Department of Agriculture.
- Annual fires and total acres include all private, state and federal lands.
- Costs are not adjusted for inflation.

### Federal Firefighting Costs (Suppression Only)

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<th>Year</th>
<th>Fires</th>
<th>Acres</th>
<th>Forest Service</th>
<th>DOI Agencies</th>
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<tr>
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<td>1,797,574</td>
<td>$184,000,000</td>
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<td>$240,436,000</td>
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<tr>
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A.6.18  *Fourth National Climate Assessment* chapter 10: changes in land cover and terrestrial biogeochemistry

A.6.18.1  **Key finding 1: changes in fundamental physical characteristics of land cover**  Changes in land use and land cover due to human activities produce physical changes in land surface albedo [a measure of light reflectivity], latent and sensible heat, and atmospheric aerosol and greenhouse gas concentrations. The combined effects of these changes have recently been estimated to account for 40% ± 16% of the human-caused global radiative forcing from 1850 to present day (*high confidence*). In recent decades, land use and land cover changes have turned the terrestrial biosphere (soil and plants) into a net “sink” for carbon (drawing down carbon from the atmosphere), and this sink has steadily increased since 1980 (*high confidence*). Because of the uncertainty in the trajectory of land cover, the possibility of the land becoming a net carbon source cannot be excluded (*very high confidence*).

A.6.18.2  **Key finding 2: feedback from land cover changes**  Climate change and induced changes in the frequency and magnitude of extreme events (e.g., droughts, floods, and heat waves) have led to large changes in plant community structure with subsequent effects on the biogeochemistry of terrestrial ecosystems. Uncertainties about how climate change will affect land cover change make it difficult to project the magnitude and sign of future climate feedbacks from land cover changes (*high confidence*).

A.6.18.3  **Key finding 3: variability of changes in growing season**  Since 1901, regional averages of both the consecutive number of frost-free days and the length of the corresponding growing season have increased for the seven contiguous U.S. regions used in this assessment. However, there is important variability at smaller scales, with some locations actually showing decreases of a few days to as much as one to two weeks. Plant productivity has not increased commensurate with the increased number of frost-free days or with the longer growing season due to plant-specific temperature thresholds, plant–pollinator dependence, and seasonal limitations in water and nutrient availability (*very high confidence*). Future consequences of changes to the growing season for plant productivity are uncertain. [Examples of problems caused by a timing mismatch between plants and pollinators caused by early onset of spring have indeed been observed.]

A.6.18.4  **Key finding 4: confirmation and quantification of the urban heat island effect**  Recent studies confirm and quantify that surface temperatures are higher in urban areas than in surrounding rural areas for a number of reasons, including the concentrated release of heat from buildings, vehicles, and industry. In the United States, this urban heat island effect results in daytime temperatures 0.9°–7.2°F (0.5°–4.0°C) higher and

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344 *Latent heat* denotes the heat transfer required to bring about a change in phase, e.g., conversion of a solid into a liquid or vapor at constant temperature. The term *heat of fusion* means the same, but is typically used only for a liquid-solid rather than a liquid-vapor transition. *Sensible heat* is heat exchanged that results in a change in temperature, but not phase.

nighttime temperatures 1.8°–4.5°F (1.0°–2.5°C) higher in urban areas, with larger temperature differences in humid regions (primarily in the eastern United States) and in cities with larger and denser populations. The urban heat island effect will strengthen in the future as the structure, spatial extent, and population density of urban areas change and grow (high confidence).

A.6.19 Agricultural and forest losses—additional details

Changes in water supply and water quality will also impact agriculture in the United States. Additionally, increased heat and the problems exacerbates such as pests, crop diseases, and weather extremes, will all negatively impact crop and livestock production and quality. For example, climate change in the United States has produced warmer summers, which has made it possible for the mountain pine beetle to produce two generations of beetles in a single summer season, where it had previously only been able to produce one generation. In Alaska, the spruce beetle is maturing in one year, where previously it had taken two years. The expansion of the forest beetle population has killed millions of hectares of trees across the United States and Canada and

[t]he economic loss goes well beyond the lumber value (millions of board-feet) of the trees, as tourism revenue is highly dependent on having healthy, attractive forests. Hundreds of millions of dollars are being spent to mitigate the impacts of beetle infestation in British Columbia alone . . . .

Adding further complexity to the climate-beetle-forest relationship in the contiguous United States, increased beetle populations have increased incidences of a fungus they transmit (pine blister rust, Cronartium ribicola).

Agriculture is highly susceptible to climate change, and higher temperatures generally reduce yields of desirable crops while promoting pest and weed proliferation as “[m]any weeds respond more positively to increasing CO₂ than most cash crops . . . .” “Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security.”

Global climate change is predicted to decrease crop yields, increase crop prices, and decrease worldwide calorie availability. By 2050 this is projected to increase child malnutrition by 20%. Aggressive agricultural productivity investments are needed to raise calorie

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347 Ibid., pp. 154-155.


349 Ibid., p. 15.


consumption enough to offset the negative impacts of climate change on the health and well-being of children.  

A.6.19.1 Can food sources keep up with climate change? Global warming could rapidly threaten grasses, which include staple foods that provide roughly half of the calories consumed by humans. The following abstract sheds light on the pivotal question whether nature can keep up with the unprecedented rate at which climate change in the Anthropocene is progressing.

Climate change may soon threaten much of global biodiversity, especially if species cannot adapt to changing climatic conditions quickly enough. A critical question is how quickly climatic niches change, and if this speed is sufficient to prevent extinction as climates warm. Here, we address this question in the grass family (Poaceae). Grasses are fundamental to one of Earth’s most widespread biomes (grasslands), and provide roughly half of all calories consumed by humans (including wheat, rice, corn and sorghum). We estimate rates of climatic niche change in 236 species and compare these with rates of projected climate change by 2070. Our results show that projected climate change is consistently faster than rates of niche change in grasses, typically by more than 5000-fold for temperature-related variables. Although these results do not show directly what will happen under global warming, they have troubling implications for a major biome and for human food resources.

A.6.20 Fourth National Climate Assessment chapter 11: arctic changes and their effects on Alaska and the rest of the U.S.

A.6.20.1 Key finding 1: temperature in Alaska is increasing at twice the global rate. Annual average near-surface air temperatures across Alaska and the Arctic have increased over the last 50 years at a rate more than twice as fast as the global average temperature (very high confidence).

A.6.20.2 Key finding 2: Alaskan permafrost is heating up and possibly releasing run-away amounts of carbon dioxide and methane. Rising Alaskan permafrost temperatures are causing permafrost to thaw and become more discontinuous; this process releases additional carbon dioxide and methane, resulting in an amplifying feedback and additional warming (high confidence). The overall magnitude of the permafrost–carbon feedback is uncertain; however, it is clear that these emissions have the potential to compromise the ability to limit global temperature increases. [Notice the understated language used to describe the threat of irreversible, run-away climate change; for more on this see section A.7, page 109.]

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352 Nelson et al., supra note 351, p. vii.
A.6.20.3 Key finding 3: accelerated melting of Alaskan and arctic cryosphere
Arctic land and sea ice loss observed in the last three decades continues, in some cases accelerating (very high confidence). It is virtually certain that Alaska glaciers have lost mass over the last 50 years, with each year since 1984 showing an annual average ice mass less than the previous year. Based on gravitational data from satellites, average ice mass loss from Greenland was \( \sim 269 \text{ Gt per year} \) between April 2002 and April 2016, accelerating in recent years (high confidence). Since the early 1980s, annual average arctic sea ice has decreased in extent between 3.5% and 4.1% per decade, become thinner by between 4.3 and 7.5 feet, and began melting at least 15 more days each year. September sea ice extent has decreased between 10.7% and 15.9% per decade (very high confidence). Arctic-wide ice loss is expected to continue through the 21st century, very likely resulting in nearly sea ice-free late summers by the 2040s (very high confidence). [See important specifics in sections A.6.21.1 and A.6.21.2, pages 90 and 91.]

A.6.20.4 Key finding 4: human activities cause decline of cryosphere in northern hemisphere
It is very likely that human activities have contributed to observed arctic surface temperature warming, sea ice loss, glacier mass loss, and Northern Hemisphere snow extent decline (high confidence).

A.6.20.5 Key finding 5: arctic warming impacts mid-latitude weather patterns
Atmospheric circulation patterns connect the climates of the Arctic and the contiguous United States. Evidenced by recent record warm temperatures in the Arctic and emerging science, the midlatitude circulation has influenced observed arctic temperatures and sea ice (high confidence). However, confidence is low regarding whether or by what mechanisms observed arctic warming may have influenced the midlatitude circulation and weather patterns over the continental United States. The influence of arctic changes on U.S. weather over the coming decades remains an open question with the potential for significant impact. [For a recent study see L. Sun, M. Alexander, and C. Deser, “Evolution of the global coupled climate response to Arctic sea ice loss during 1990-2090 and its contribution to climate change.” In: Journal of Climate in print.0 (2018), null. DOI: 10.1175/JCLI-D-18-0134.1. eprint: https://doi.org/10.1175/JCLI-D-18-0134.1. URL: https://doi.org/10.1175/JCLI-D-18-0134.1; further details are in section A.11.2, page 139.]

A.6.21 Glaciers, sea ice, and permafrost—additional details
A.6.21.1 Arctic report card 2016
A new NOAA-sponsored report\textsuperscript{355} released in December of 2016 showed that unprecedented warming air temperature in 2016 over the Arctic contributed to a record-breaking delay in the fall sea ice freeze-up, leading to extensive melting of Greenland ice sheet and land-based snow cover.

Rarely have we seen the Arctic show a clearer, stronger or more pronounced signal of persistent warming and its cascading effects on the environment than this year,
said Jeremy Mathis, director of NOAA’s Arctic Research Program.\textsuperscript{356}


\textsuperscript{356}Ibid.
Some major findings of the report are:

**Higher air temperature:** Average annual air temperature over land areas was the highest in the observational record, representing a 3.5°C (6.3°F) increase since 1900. Arctic temperatures have increased twice as fast as global increases, a phenomenon known as *Arctic amplification.*

**Greenland ice sheet mass loss:** The Greenland ice sheet continued to lose mass in 2016 on a trajectory consistent with the increase in greenhouse gas emissions.

**Above-average Arctic Ocean temperature:** Sea surface temperature in August 2016 was 5°C (9°F) above the average for 1982–2010 in the Barents and Chukchi seas and off the east and west coasts of Greenland.

**Record low sea ice:** The Arctic sea ice minimum extent from mid-October 2016 to late November 2016 was the lowest since the satellite record began in 1979 and 28% less than the average for 1981–2010 in October. Arctic ice is thinning, which increases the heat flux from the ocean to atmosphere in autumn and early winter. Multi-year ice now makes up less than one quarter, while the remaining three quarters consist of the ice cover is more fragile, thinner first-year ice. By comparison, in 1985 close to half of ice cover was multi-year ice.

It is hard to overstate the disturbing nature of these developments, as explained here:357

The Arctic plays an important role in effecting global climate change and is therefore called the “weather kitchen.” Arctic ice formations serving as natural temperature regulators reflect sunlight and therefore prevent the Earth from overheating.

### A.6.21.2 Arctic report card 2017

The headline of 2017 Arctic Report Card reads: “Arctic shows no sign of returning to reliably frozen region of recent past decades.”358 We quote the highlights of the report:

- The average surface air temperature for the year ending September 2017 is the 2nd warmest since 1900; however, cooler spring and summer temperatures contributed to a rebound in snow cover in the Eurasian Arctic, slower summer sea ice loss, and below-average melt extent for the Greenland ice sheet.
- The sea ice cover continues to be relatively young and thin with older, thicker ice comprising only 21% of the ice cover in 2017 compared to 45% in 1985.
- In August 2017, sea surface temperatures in the Barents and Chukchi seas were up to 4°C warmer than average, contributing to a delay in the autumn freeze-up in these regions.

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A SCIENTIFIC BACKGROUND—DETAILS

- Pronounced increases in ocean primary productivity, at the base of the marine food web, were observed in the Barents and Eurasian Arctic seas from 2003 to 2017.
- Arctic tundra is experiencing increased greenness and record permafrost warming.
- Pervasive changes in the environment are influencing resource management protocols, including those established for fisheries and wildfires.
- The unprecedented rate and global reach of Arctic change disproportionately affect the people of northern communities, further pressing the need to prepare for and adapt to the new Arctic.

A.6.21.3 Cryosphere continued A recent publication contains yet another aspect of these developments in the Arctic, namely that “[h]eavy ice conditions along Canada’s east coast during spring 2017 presented hazardous conditions for the maritime industry at a time of year when vessels typically do not need to contend with sea ice.”

Next, we discuss similar disconcerting developments pertaining to the danger of run-away climate change and more specifically to the rapid decay of the Pine Island, Thwaites, and other glaciers discussed in section A.7, page 109.

As expected, mountain glaciers, which are the source of freshwater for hundreds of millions of people, are receding worldwide because of increasing temperatures. In 2010, Glacier National Park in Montana had only twenty-five glaciers larger than twenty-five acres, down from one hundred and fifty in 1850. These glaciers may be completely gone in the coming decades. Mountain glaciers are in retreat all over the world. This includes glaciers on Mount Kilimanjaro, in the Himalayas and the Alps (99% in retreat), glaciers in Peru and Chile (92% in retreat), and glaciers in the United States. In the Brooks Range of northern Alaska, 100% of the glaciers are in retreat, and in southeastern Alaska this number is 98%.

Although responsible for a relatively minor contribution to sea level rise, the melting of mountain glaciers is particularly serious in areas that rely on snow melt for irrigation and drinking water supply. In effect, a large snow pack or glacier acts as a water reservoir, accumulating water in the form of ice and snow through the winter and spring, and releasing it in the summer when rainfall is low or absent. The water systems of the western United States (particularly California) and the Andean nations of Peru and Chile, among other places, all rely heavily on these natural water storage systems. In addition to providing a more reliable water supply, the storing of precipitation as ice and snow helps moderate...

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360 supra note 44, p. 111.


363 Id., p. 158.

364 supra note 361.

365 Thompson, “Climate Change: The Evidence and Our Options,” supra note 362, p. 158.

366 Id., p. 164.

367 Id., p. 164.
potential flooding. Yet as temperatures go up, not only will these areas lose this supplemental form of water storage, but also severe flooding is likely to increase. The reason for that is that when rain falls on snow, it accelerates the melting of glaciers and snow packs.\footnote{January was 3rd warmest on record for the globe. National Oceanic and Atmospheric Administration. Feb. 16, 2017. URL: \url{http://www.noaa.gov/news/january-was-3rd-warmest-on-record-for-globe} (visited on Jan. 12, 2018).}

January 2017 was third warmest on record for the globe. Record low January Arctic and Antarctic sea ice extents were recorded.\footnote{As of this writing (12/21/2017) the web site where this document should be available is “being updated” and not functional. The document had to be retrieved from the INTERNET ARCHIVE Wayback Machine \textit{Climate Change Indicators in the United States, 2014–Third Edition. EPA 430-R-14-004. U.S. Environmental Protection Agency}. 2014. URL: \url{https://web.archive.org/web/20170427131943/https://www3.epa.gov/climatechange/pdfs/climateindicators-full-2014.pdf} (visited on Dec. 21, 2017), p. 58.} As mentioned, Arctic sea ice plays an important role in stabilizing the global climate because it reflects back into space much of the solar radiation that the region receives. More explicitly, as the Environmental Protection Agency puts it:\footnote{Drijfhout \textit{et al.}, supra note 61.}

\begin{quote}
The extent of area covered by Arctic sea ice is an important indicator of changes in global climate because warmer air and water temperatures are reducing the amount of sea ice present. Because sea ice reflects more sun light than liquid water, it plays a significant role in the Earth’s energy balance and keeping polar regions cool.
\end{quote}

In contrast, relatively dark-colored ocean water absorbs much more light from the sun, thus heating up and amplifying global warming. As Arctic sea ice decreases in area, the region is less capable of stabilizing the global climate. The result is a positive feedback loop that aggravates global warming.

For feedback in excess of a (typically unknown) critical threshold, run-away climate change results. The existence of critical thresholds is familiar to all of us from the howling sound resulting from audio amplifier turned up too high. The pertinent analogue of such a threshold is the low-end critical area of sea ice, a tipping point “notoriously difficult to foresee.”\footnote{section B3, IPCC, supra note 240, p. 9.} as mentioned previously on page 18 in section A.7, page 109.

Of course, we have known all of this for a long time, and Intergovernmental Panel on Climate Change (IPCC)’s \textit{Fifth Assessment Report} sums the melting of the cryosphere up as:\footnote{section B3, IPCC, supra note 240, p. 9.}

- The average rate of ice loss\footnote{The average rate of ice loss\textsuperscript{8} [superscripts refer to notes at the end of this quote] from glaciers around the world, excluding glaciers on the periphery of the ice sheets,\textsuperscript{9} was very likely 226 [91 to 361] Gt yr\textsuperscript{−1} over the period 1971 to 2009, and very likely 275 [140 to 410] Gt yr\textsuperscript{−1} over the period 1993 to 2009.\textsuperscript{10} .
- The average rate of ice loss from the Greenland ice sheet has very likely substantially increased from 34 [6 to 74] Gt yr\textsuperscript{−1} over the period 1992 to 2001 to 215 [157 to 274] Gt yr\textsuperscript{−1} over the period 2002 to 2011 .
- The average rate of ice loss from the Antarctic ice sheet has likely increased from 30 [37 to 97] Gt yr\textsuperscript{−1} over the period 1992–2001 to 147 [72 to 221] Gt yr\textsuperscript{−1} over the period 2002 to 2011. There is very high confidence that these

\footnote{The average rate of ice loss\textsuperscript{8} [superscripts refer to notes at the end of this quote] from glaciers around the world, excluding glaciers on the periphery of the ice sheets,\textsuperscript{9} was very likely 226 [91 to 361] Gt yr\textsuperscript{−1} over the period 1971 to 2009, and very likely 275 [140 to 410] Gt yr\textsuperscript{−1} over the period 1993 to 2009.\textsuperscript{10} .
- The average rate of ice loss from the Greenland ice sheet has very likely substantially increased from 34 [6 to 74] Gt yr\textsuperscript{−1} over the period 1992 to 2001 to 215 [157 to 274] Gt yr\textsuperscript{−1} over the period 2002 to 2011 .
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losses are mainly from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica.

• The annual mean Arctic sea ice extent decreased over the period 1979 to 2012 with a rate that was very likely in the range 3.5 to 4.1% per decade (range of 0.45 to 0.51 million km$^2$ per decade), and very likely in the range 9.4 to 13.6% per decade (range of 0.73 to 1.07 million km$^2$ per decade) for the summer sea ice minimum (perennial sea ice). The average decrease in decadal mean extent of Arctic sea ice has been most rapid in summer (high confidence); the spatial extent has decreased in every season, and in every successive decade since 1979 (high confidence). There is medium confidence from reconstructions that over the past three decades, Arctic summer sea ice retreat was unprecedented and sea surface temperatures were anomalously high in at least the last 1,450 years.

• It is very likely that the annual mean Antarctic sea ice extent increased at a rate in the range of 1.2 to 1.8% per decade (range of 0.13 to 0.20 million km$^2$ per decade) between 1979 and 2012. There is high confidence that there are strong regional differences in this annual rate, with extent increasing in some regions and decreasing in others.

• There is very high confidence that the extent of Northern Hemisphere snow cover has decreased since the mid-20th century. Northern Hemisphere snow cover extent decreased 1.6 [0.8 to 2.4] % per decade for March and April, and 11.7 [8.8 to 14.6] % per decade for June, over the 1967 to 2012 period. During this period, snow cover extent in the Northern Hemisphere did not show a statistically significant increase in any month.

• There is high confidence that permafrost temperatures have increased in most regions since the early 1980s. Observed warming was up to 3°C in parts of Northern Alaska (early 1980s to mid-2000s) and up to 2°C in parts of the Russian European North (1971 to 2010). In the latter region, a considerable reduction in permafrost thickness and areal extent has been observed over the period 1975 to 2005 (medium confidence).

• Multiple lines of evidence support very substantial Arctic warming since the mid-20th century.

8 All references to ‘ice loss’ or ‘mass loss’ refer to net ice loss, i.e., accumulation minus melt and iceberg calving.

9 For methodological reasons, this assessment of ice loss from the Antarctic and Greenland ice sheets includes change in the glaciers on the periphery. These peripheral glaciers are thus excluded from the values given for glaciers.

10 100 Gt yr$^{-1}$ of ice loss is equivalent to about 0.28 mm yr$^{-1}$ of global mean sea level rise.

Substantial methane releases from thawing permafrost have been detected in Alaska and Siberia:\supra note 370, p. 48.

Methane emissions have been detected from Alaskan lakes underlain by permafrost, ... and measurements suggest potentially even greater releases from
thawing methane hydrates in the Arctic continental shelf of the East Siberian Sea . . . . However, the response times of Arctic methane hydrates to climate change are quite long relative to methane’s lifetime in the atmosphere (about a decade) . . . . More generally, the importance of Arctic methane sources relative to other methane sources, such as wetlands in warmer climates, is largely unknown. The potential for a self-reinforcing feedback between permafrost thawing and additional warming contributes additional uncertainty to the high end of the range of future warming. [Ellipses indicate omitted references.]

Because much of the Arctic permafrost overlays old peat bogs, melting of permafrost may release methane that will further increase global warming:

Permafrost is permanently frozen ground, mainly found in the high latitudes of the Arctic. Permafrost, including the sub-sea permafrost on the shallow shelves of the Arctic Ocean, contains old organic carbon deposits. Some are relics from the last glaciation, and *hold at least twice the amount of carbon currently present in the atmosphere as carbon dioxide* (CO$_2$) [emphasis added]. Should a sizable fraction of this carbon be released as methane and CO$_2$, it would increase atmospheric concentrations, which would lead to higher atmospheric temperatures. That in turn would cause yet more methane and CO$_2$ to be released, creating a positive feedback, which would further amplify global warming.

Beginning in late 2000, the Jakobshavn Isbræ Glacier (which has a major influence over the mass of the Greenland ice sheet) lost significant amounts of ice. The following abstract is a clear demonstration of the complexity, as discussed in section A.4, page 55, of such events and the near-impossibility of predicting them accurately:

Observations over the past decades show a rapid acceleration of several outlet glaciers in Greenland and Antarctica. One of the largest changes is a sudden switch of Jakobshavn Isbræ, a large outlet glacier feeding a deep-ocean fjord on Greenland’s west coast, from slow thickening to rapid thinning . . . in 1997, associated with a doubling in glacier velocity . . . . Suggested explanations for the speed-up of Jakobshavn Isbræ include increased lubrication of the ice–bedrock interface as more meltwater has drained to the glacier bed during recent warmer summers . . . and weakening and break-up of the floating ice tongue that buttressed the glacier . . . . Here we present hydrographic data that show a sudden increase in subsurface ocean temperaturesurface temperature in 1997 along the entire west coast of Greenland, suggesting that the changes in Jakobshavn Isbræ were instead triggered by the arrival of relatively warm water originating from the Irminger Sea near Iceland. We trace these oceanic changes back to changes in the atmospheric circulation in the North Atlantic region. We conclude that the prediction of future rapid dynamic responses of other outlet glaciers to climate change will require an improved understanding of the effect of changes in regional ocean and atmosphere circulation on the delivery of warm subsurface waters to the periphery of the ice sheets. [Ellipses indicate omitted references.]
The 2002 collapse of the Larsen Ice Shelf, which had existed for at least 11,000 years, was “unprecedented in respect to both area and time.” The “sudden and complete disintegration” of the Larsen Ice Shelf took a mere 35 days. Less obviously dramatic, but more profound is what happened to the glaciers that were held in place by the Larsen Ice Shelf, which functioned as a “bookend.”

Observations by many scientists have shown a substantial increase in the velocity of tributary glaciers and a lowering of the glacier surface after the disappearance of adjacent ice shelves, confirming the buttressing role of the ice shelves. The map portrays one of the most rapidly changing areas on Earth, and the changes in the map area are widely regarded as among the most profound, unambiguous examples of the effects of global warming on Earth.

Record-setting events grab attention, but of more fundamental importance is understanding of the underlying mechanisms that can trigger disruptions. An example of that is discussed in Forget That Big Iceberg—A Smaller One in the Arctic Is More Troubling:

The world saw headlines about one of the largest icebergs ever calved a few weeks ago. But a smaller one on the other end of the globe might have bigger consequences. The chunk of ice, which broke free in the Arctic last week [July 2017], is more worrisome to climate scientists who are watching one of Earth’s largest glaciers shed pieces in a way that stands to raise sea levels.

Compared with the Delaware-sized iceberg that split off of West Antarctica earlier this month, this one is almost paltry — the size of three Manhattans or so. It came off the ice shelf that buttresses the Petermann Glacier at the height of seasonal warming in the Arctic region.

... 

“It’s a small, steady, measurable drip, and it’s this drip, drip, drip that is eroding these glaciers,” Muenchow said. “It’s not always what you see and what’s a dramatic event, like an iceberg breaking up. It’s this year-round drip, drip, drip by the ocean underneath that really determines what’s happening by weakening the ice shelf from below.”

In a recent review in Nature Shepherd et al. report:

Reductions in the thickness and extent of floating ice shelves have disturbed inland ice, triggering retreat, acceleration and drawdown of marine-terminating glaciers.

A team of 84 scientists from 44 international organizations have combined 24 satellite observations of change in the Antarctic with greater precision and in greater detail than

studies so far. The news is ominous: Antarctica’s melting is speeding up more rapidly than expected by a factor in the range from three to five from 1992 until 2017,\textsuperscript{381} which vastly exceeds the doubling time in the three to four decade range expected the basis of the exponential increase in global greenhouse gas emissions discussed previously on page 17.

Recent modeling suggest the possibility of “future extreme outcomes.”\textsuperscript{382} Similarly, observations shed light on a mechanisms for the disintegration of both the West and the East Antarctic ice sheets, causing multi-meter sea-level rise.\textsuperscript{383}

We identify entrances to the ice-shelf cavity below depths of 400 to 500 m that could allow intrusions of warm water if the vertical structure of inflow is similar to nearby observations. Radar sounding reveals a previously unknown inland trough that connects the main ice-shelf cavity to the ocean. If thinning trends continue, a larger water body over the trough could potentially allow more warm water into the cavity, which may, eventually, lead to destabilization of the low-lying region between Totten Glacier and the similarly deep glacier flowing into the Reynolds Trough.

A.6.21.4 The snow, water, ice, and permafrost (SWIPA) report The SWIPA report\textsuperscript{384} mentions that the rate of land-based ice loss in the Arctic (mostly from Greenland) in recent years has increased by almost a factor of two over a period of seven years.\textsuperscript{385} This acceleration in the rate of ice loss is particularly disconcerting, given that one would expect a doubling time of three to four decades, as discussed in on page 53 in section A.3.

The SWIPA report is among the few sources—also see section A.6.3—acknowledging that the scientific literature may miss certain aspects of climate change. As the report states:\textsuperscript{386}

TRADITIONAL AND LOCAL KNOWLEDGE

The SWIPA scientific assessment is based primarily on peer-reviewed observations, methods, and studies, which in many cases include contributions from traditional and local knowledge. However, it is recognized that this approach does not necessarily capture all relevant knowledge held by Indigenous and local communities.

Indeed as Cochran et al. mention:\textsuperscript{387}

Despite a keen awareness of climate change, northern Indigenous Peoples have had limited participation in climate-change science due to limited access, power imbalances, and differences in worldview.


\textsuperscript{383}J. S. Greenbaum et al., “Ocean access to a cavity beneath Totten Glacier in East Antarctica.” In: Nature Geoscience 8 (2015), p. 294. DOI: 10.1038/ngeo2388.


\textsuperscript{385}Id., p. 4.

\textsuperscript{386}Id., p. 4.

Once again, the importance of the recurring theme of a white, sunlight reflecting surface, whether it be snow or ice, cannot be over-emphasized. The *State of the Cryosphere* quotes various publications included below and states:  

Snow cover is an important climate change variable because of its influence on energy and moisture budgets. Snow cover accounts for the large differences between summer and winter land surface albedo [a measure of light reflectivity], both annually and inter-annually. Snow may reflect as much as 80 to 90 percent of the incoming solar energy, whereas a snow-free surface such as soil or vegetation may reflect only 10 to 20 percent. A warming trend results in decreased snow cover. With the resulting decrease in reflected energy, absorption of solar radiation increases, adding heat to the system, thereby causing even more snow to melt. This is the classic temperature-albedo feedback mechanism; it is a “positive feedback” because it reinforces itself. Surface temperature is highly dependent on the presence or absence of snow cover, and temperature trends have been linked to changes in snow cover (Groisman et al. 1994, Brown and Robinson 2011, Peng *et al.* 2013).

In addition to the albedo effect, snow cover represents a significant heat sink during the melt period of the seasonal cycle due to a relatively high latent heat of fusion [the heat required to melt ice]. As a result, the seasonal snow cover provides a major source of energy to the total climate system, as it consumes large amounts of energy with little or no fluctuation in temperature as snow crystals melt.

**A.6.22 Fourth National Climate Assessment chapter 12: sea level rise**

**A.6.22.1 Key finding 1: rate of sea level rise is unprecedented on a 3,000 year timescale** Global mean sea level (GMSL) has risen by about 7–8 inches (about 16–21 cm) since 1900, with about 3 of those inches (about 7 cm) occurring since 1993 (very high confidence). Human-caused climate change has made a substantial contribution to GMSL [global mean sea level] rise since 1900 (high confidence), contributing to a rate of rise that is greater than during any preceding century in at least 2,800 years (medium confidence). [For specifics see section A.6.23.

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[392] See note 344

A.6.22.2 Key finding 2: continued sea level rise “baked in” beyond 2100 Relative to the year 2000, GMSL [global mean sea level] is very likely to rise by 0.3–0.6 feet (9–18 cm) by 2030, 0.5–1.2 feet (15–38 cm) by 2050, and 1.0–4.3 feet (30–130 cm) by 2100 (very high confidence in lower bounds; medium confidence in upper bounds for 2030 and 2050; low confidence in upper bounds for 2100). Future pathways have little effect on projected GMSL [global mean sea level] rise in the first half of the century, but significantly affect projections for the second half of the century (high confidence). Emerging science regarding Antarctic ice sheet stability suggests that, for high emission scenarios, a GMSL [global mean sea level] rise exceeding 8 feet (2.4 m) by 2100 is physically possible, although the probability of such an extreme outcome cannot currently be assessed. Regardless of pathway, it is extremely likely that GMSL [global mean sea level] rise will continue beyond 2100 (high confidence).

A.6.22.3 Key finding 3: sea level rise will disproportionately affect coast of United States Northeast Relative sea level (RSL) rise in this century will vary along U.S. coastlines due, in part, to changes in Earth’s gravitational field and rotation from melting of land ice, changes in ocean circulation, and vertical land motion (very high confidence). For almost all future GMSL [global mean sea level] rise scenarios, RSL [relative sea level] rise is likely to be greater than the global average in the U.S. Northeast and the western Gulf of Mexico. In intermediate and low GMSL [global mean sea level] rise scenarios, RSL [relative sea level] rise is likely to be less than the global average in much of the Pacific Northwest and Alaska. For high GMSL [global mean sea level] rise scenarios, RSL [relative sea level] rise is likely to be higher than the global average along all U.S. coastlines outside Alaska. Almost all U.S. coastlines experience more than global mean sea level rise in response to Antarctic ice loss, and thus would be particularly affected under extreme GMSL [global mean sea level] rise scenarios involving substantial Antarctic mass loss (high confidence).

A.6.22.4 Key finding 4: increased depth and frequency tidal floods in Atlantic and Gulf cities As sea levels have risen, the number of tidal floods each year that cause minor impacts (also called “nuisance floods”) have increased 5- to 10-fold since the 1960s in several U.S. coastal cities (very high confidence). Rates of increase are accelerating in over 25 Atlantic and Gulf Coast cities (very high confidence). Tidal flooding will continue increasing in depth, frequency, and extent this century (very high confidence). [Threats of sea level rise in Asia are discussed on page 118. Also see section A.6.23, page 100.]

A.6.22.5 Key finding 5: increase in frequency and extent of extreme flooding associated with coastal storms and nor’easters Assuming storm characteristics do not change, sea level rise will increase the frequency and extent of extreme flooding associated with coastal storms, such as hurricanes and nor’easters (very high confidence). A projected increase in the intensity of hurricanes in the North Atlantic (medium confidence) could increase the probability of extreme flooding along most of the U.S. Atlantic and Gulf Coast states beyond what would be projected based solely on RSL [relative sea level] rise. However, there is low confidence in the projected increase in frequency of intense Atlantic hurricanes, and the associated flood risk amplification and flood effects could be offset or amplified by such factors as changes in overall storm frequency or tracks. [For details see section A.6.23, page 100.]
A.6.23 Sea level rise—additional details

Recently, Kopp et al. wrote a paper with the following plain language summary:394

Recent ice-sheet modeling papers have introduced new physical mechanisms—specifically the hydrofracturing of ice shelves and the collapse of ice cliffs—that can rapidly increase ice-sheet mass loss from a marine-based ice-sheet, as exists in much of Antarctica. This paper links new Antarctic model results into a sea-level rise projection framework to examine their influence on global and regional sea-level rise projections and their associated uncertainties, the potential impact of projected sea-level rise on areas currently occupied by human populations, and the implications of these projections for the ability to constrain future changes from present observations. Under a high greenhouse gas emission future, these new physical processes increase median projected 21st century GMSL [global mean sea level] rise from ∼80 to ∼150 cm. Revised median RSL [relative sea level] projections for a high-emissions future would, without protective measures, by 2100 submerge land currently home to more than 153 million people.

Fig. 18 explains the meaning of a sea level “significantly higher than today.” This a rather detached, recurring phrase in this chapter. During the Pliocene, 3–5 million years ago, sea level was about 80 feet (25 meters) higher than today. The temperature was 1.8–3.6°F (1–2°C) higher than preindustrial, while CO₂ was in the 350–400 parts per million range. These numbers are dreadfully close to Earth’s “vital statistics” today.

Figure 18: This diagram shows sea level position for the last five million years since the end of the Miocene and the beginning of the Pliocene. Sea level is established here using an “albedo proxy.” (Credit: Root Routledge, created from source information and graphs from James Hansen publications. Copyright Root Routledge, but available for non-commercial distribution.)

As discussed in section A.6.5, page 67, CO₂ levels have been increasing and driving the climate system exponentially with a doubling time on the order of three to four decades. One therefore expects that global sea levels will, apart from the typical superimposed climate

system oscillations mentioned on page 56, will also rise exponentially, i.e., at an accelerating rate, as has indeed been observed.\textsuperscript{395}

As Hansen \textit{et al.} spell out at length,\textsuperscript{396} ice melt doubling times of 10, 20, or 40 years would result in sea level rise of several meters in 50, 100, or 200 years. As revealed by recent ice melting, it appears that the ice melt doubling time is at the low end of the 10–40 year range.\textsuperscript{397} It is vital to keep this timescale in mind when considering the “methane as a bridge fuel” issue. For more specifics on the latter see section A.9, page 122.

Rising seas, brought about by the melting of polar icecaps and glaciers, as well as by thermal expansion of the warming oceans, will cause flooding in coastal and low-lying areas, as discussed above in section A.6.22.4, page 99. The combination of rising sea levels and more severe storms creates conditions conducive to severe storm surges during high tides. In coastal communities this can overwhelm coastal defenses (such as levees and sea walls), as witnessed during hurricane Katrina and hurricane Sandy. Because of the long persistence time of CO\textsubscript{2} in the climate system, without immediate and rapid reductions in CO\textsubscript{2} emissions, humanity will lock in catastrophic consequences, such as multi-meter sea level rise, and loss of coastal cities. “The economic and social cost of losing functionality of all coastal cities is practically incalculable.”\textsuperscript{398} Indeed, as Hansen \textit{et al.} phrase it, “a strategy of relying on adaptation to such consequences will be unacceptable to most of humanity, . . . .”\textsuperscript{399}

It may be too early for a full-fledged attribution study\textsuperscript{400} of the relationship of Hurricanes Harvey, Maria, and Irma to climate change, but it is evident that the 2017 hurricane season, not in the last place because of already present sea level rise, did extraordinary damage.

We also draw attention to the fact that sea level rise is not uniform across the globe, because it depends on local variables such as ocean temperature and current.\textsuperscript{401} An example of this geographic variability of particular relevance to the United States Northeast coast is the impact of a slowdown of the Atlantic Meridional Overturning Circulation (AMOC), as mentioned in section A.7.1, page 113. Also changes in the earth’s gravitational field will introduce non-uniformity, as discussed in section A.6.22.3, page 99. More explicitly, the melting of ice sheets will redistribute the earth’s mass and change the shape of the earth and its gravitational field will change differently in different places.

Clearly, the most vulnerable lands are low-lying islands, river deltas, and areas that already lie below sea level possibly because of land subsidence.\textsuperscript{402} Observations and modeling show that the immediate threats to the United States from rising seas are the most severe on the Gulf and Atlantic Coasts—see section A.6.22.4, page 99. Worldwide, hundreds of millions of people live in river deltas and near vulnerable coastlines along the southern and western coasts of Asia, where rivers of Himalayan origin flow into the Indian and Pacific

\begin{footnotesize}
\begin{enumerate}
\item J. Hansen \textit{et al.}, “Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2°C global warming could be dangerous.” In: \textit{Atmospheric Chemistry and Physics} 16.6 (2016), pp. 3761–3812. DOI: 10.5194/acp-16-3761-2016. URL: \url{https://www.atmos-chem-phys.net/16/3761/2016/}.
\item \textit{Id.}, p. 3761.
\item \textit{Id.}, p. 3762.
\item \textit{Id.}, p. 3762.
\item Hansen, M. Sato, and Ruedy, \textit{supra} note 248; Coumou and Rahmstorf, \textit{supra} note 245; Otto, \textit{supra} note 249.
\item \textit{supra} note 44, p. 121.
\end{enumerate}
\end{footnotesize}
If carbon pollution is not quickly abated, there is near-certainty that humanity will experience multi-meter sea level rise this century, submerging much of the eastern seaboard of the U.S., as well as low lying areas of Europe, the Far East, and the Indian subcontinent. For further details the possible geopolitical implications see page 118 in section A.8.

However, there is more at stake than social stability, war and peace. Low-lying lands, especially, are vulnerable to sea level rise:

Today, rising sea levels are submerging low-lying lands, eroding beaches, converting wetlands to open water, exacerbating coastal flooding, and increasing the salinity of estuaries and freshwater aquifers.

As wetlands are inundated, further impacts from sea level rise will multiply, as “protection of coastal lands and people against storm surge will be compromised.” As the Third National Climate Assessment mentions, Newtok, a Yup’ik community on the seacoast of western Alaska, is on the front lines of climate change:

“Not that long ago the water was far from our village and could not be easily seen from our homes. Today the weather is changing and is slowly taking away our village. Our boardwalks are warped, some of our buildings tilt, the land is sinking and falling away, and the water is close to our homes. The infrastructure that supports our village is compromised and affecting the health and well-being of our community members, especially our children’s health.”

—Alaska Department of Commerce and Community and Economic Development, 2012

Glacial and ice cap melting is one of the major indicators of global warming and a significant cause of global sea level change. Indeed.

There is strong recent evidence from satellites such as GRACE and from direct observations that glaciers and ice caps worldwide are losing mass relatively rapidly, contributing to the recent increase in the observed rate of sea level rise.

In addition, there is the well-known effect of thermal expansion of water which is prevalent except in a narrow temperature-pressure range and causes sea level rise.

Finally, it has long been recognized that a sufficiently big climate change may result in an abrupt tipping point and possibly irreversible, run-away climate change. In the vicinity of such a state shift, as is well known, the behavior of physical systems, of which the climates system is a particularly complex instance, as mentioned in section A.4), page 55, is nearly impossible to predict quantitatively. This unpredictability is due to high susceptibility to

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403 supra note 44, p. 159.
404 Hansen et al., “Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2°C global warming could be dangerous,” supra note 396, pp. 3761–3762, 3765, 3790, 3792.
406 Melillo, Richmond, and Yohe, supra note 77, p. 402.
407 Id., p. 518.
408 Id., p. 485.
409 Id., p. 44.
minor perturbations. The resulting state shift (tipping point) may include what are known as noise-induced transitions.\textsuperscript{410,411} As mentioned, the inability of science to make quantitatively accurate predictions about these state shifts makes the precautionary principle, discussed in more detail in section A.12, page 146, a vital ingredient in planning.\textsuperscript{412} As the Third National Climate Assessment mentions in one of its 32 instances of use of the word “tipping” with this meaning:\textsuperscript{413}

The observed drastic reduction in sea ice can also lead to a “tipping point”—a point beyond which an abrupt or irreversible transition to a different climatic state occurs. In this case, the dramatic loss of sea ice could tip the Arctic Ocean into a permanent, nearly ice-free state in summer, with repercussions that may extend far beyond the Arctic.

The 2017 Fourth National Climate Assessment tends to use “tipping elements,” and contains “tipping” 63 times. This amounts to a doubling time of three years, since the 2014 assessment, which all by itself is striking.

A.6.24 \textit{Fourth National Climate Assessment} chapter 13: ocean acidification and other ocean Changes

A.6.24.1 Key finding 1: oceans function as heat and acid sinks\textsuperscript{414} The world’s oceans have absorbed about 93\% of the excess heat caused by greenhouse gas warming since the mid-20th century, making them warmer and altering global and regional climate feedbacks. Ocean heat content has increased at all depths since the 1960s and surface waters have warmed by about 1.3°± 0.1°F (0.7°± 0.08°C) per century globally since 1900 to 2016. Under a higher [greenhouse gas emission] scenario, a global increase in average sea surface temperature of 4.9°± 1.3°F (2.7°± 0.7°C) by 2100 is projected, with even higher changes in some U.S. coastal regions. (Very high confidence)

A.6.24.2 Key finding 2: potential slowdown of the Atlantic Meridional Overturning Circulation The potential slowing of the Atlantic meridional overturning circulation (AMOC of which the Gulf Stream is one component)—as a result of increasing ocean heat content and freshwater driven buoyancy changes—could have dramatic climate feedbacks as the ocean absorbs less heat and CO\textsubscript{2} from the atmosphere. This slowing would also affect the climates of North America and Europe. Any slowing documented to date cannot be directly tied to anthropogenic forcing primarily due to lack of adequate observational data and to challenges in modeling ocean circulation changes. Under a higher [greenhouse gas emission] scenario (RCP8.5\textsuperscript{415}) in CMIP5 simulations, the AMOC weakens over the 21st century by 12\% to 54\% (low confidence). [See section A.7.1, page 113.]


\textsuperscript{412}supra note 80, Principle 15 of the.

\textsuperscript{413}Melillo, Richmond, and Yohe, \textit{supra} note 77, p. 28.


\textsuperscript{415}Wayne, \textit{supra} note 176.
A.6.24.3 Key finding 3: ocean acidification rate unparalleled in at least 66 millions years  The world’s oceans are currently absorbing more than a quarter of the CO$_2$ emitted to the atmosphere annually from human activities, making them more acidic (very high confidence), with potential detrimental impacts to marine ecosystems. In particular, higher-latitude systems typically have a lower buffering capacity against pH change, exhibiting seasonally corrosive conditions sooner than low-latitude systems. Acidification is regionally increasing along U.S. coastal systems as a result of upwelling (for example, in the Pacific Northwest) (high confidence), changes in freshwater inputs (for example, in the Gulf of Maine) (medium confidence), and nutrient input (for example, in agricultural watersheds and urbanized estuaries) (high confidence). The rate of acidification is unparalleled in at least the past 66 million years (medium confidence). Under the higher [greenhouse gas emission] scenario (RCP8.5$^{416}$), the global average surface ocean acidity is projected to increase by 100% to 150% (high confidence). [See section A.6.25, page 104.]

A.6.24.4 Key finding 4: declining oxygen levels in coastal waters  Increasing sea surface temperatures, rising sea levels, and changing patterns of precipitation, winds, nutrients, and ocean circulation are contributing to overall declining oxygen concentrations at intermediate depths in various ocean locations and in many coastal areas. Over the last half century, major oxygen losses have occurred in inland seas, estuaries, and in the coastal and open ocean (high confidence). Ocean oxygen levels are projected to decrease by as much as 3.5% under the higher [greenhouse gas emission] scenario (RCP8.5$^{417}$) by 2100 relative to preindustrial values (high confidence). [See section A.6.25. Oxygen loss of coastal waters poses a risk to Rhode Island fisheries as discussed in section A.2.4, page 35.]

A.6.25 Ocean acidification and coral reefs—additional details  The negative effects of increased CO$_2$ emissions are not limited to changes in the climate system. Rather, CO$_2$ emissions are also having a severe impact on the oceans. As it stands, the oceans absorb about 25%–30% of global CO$_2$ emissions and 80%-90% of the heat transfer caused by the earth’s radiation imbalance. This energy absorption by the oceans has greatly mitigated some of the climate change effects that CO$_2$ otherwise would have had. However, this relief comes at a great cost: the oceans are warming and rising, and the increased acidity threatens marine organisms, such as hard corals, clams and crabs, by corroding their calcium carbonate shells and skeletons.$^{418}$

The detailed chemical reactions responsible for this destructive effect are summarized in The Acid Test: Can We Save Our Oceans From CO$_2$?$^{419}$ Before listing some of its findings, we mention how a 2005 report of The Royal Academy sums up the effect of ocean acidification resulting from the increased CO$_2$ in the atmosphere:$^{420}$

Without significant action to reduce CO$_2$ emissions into the atmosphere, this may mean that there will be no place in the future oceans for many of the species

$^{416}$Wayne, supra note 176.
$^{417}$Id.
$^{419}$Id., p. 8.
and ecosystems that we know today. This is especially likely for some calcifying organisms.

The following findings are from *The Acid Test*; numbers in superscripts are references that can be found in the end notes starting on page 26 of the thoroughly sourced report.\(^{421}\)

This report highlights the following recent findings demonstrating that ocean acidification is already occurring and threatening the oceans. It also identifies the likely consequences of continued carbon dioxide emissions for oceans and marine ecosystems.

- Carbon dioxide in the atmosphere is higher than it has been for 800,000 years and probably for much longer.\(^{12}\) [Note: the World Meteorological Organization reports that the current CO\(_2\) level last occurred in the mid-Pliocene (3–5 millions years ago) when temperatures were 2–3 °C (4–8 °F) and sea levels 10–20 m (30–60 feet) higher than today.\(^{422}\)]
- The acidity of the ocean surface has increased 30 percent since before the Industrial Revolution.\(^{13}\) If current trends continue, it could rise by another 100 percent by the end of this century,\(^{14}\) exceeding the levels of the past 20 million years.\(^{15}\)
- The increased amount of carbon dioxide the oceans are absorbing alters the movement of nutrients and chemicals in the oceans and has wide-ranging effects on ecosystems and marine life.\(^{16}\)
- The higher acidity will also affect growth, reproduction, disease resistance and other biological and physiological processes in many species.\(^{21}\)
- Many species will be unable to adapt to the rapid changes in ocean acidity and carbonate concentrations, especially those that build calcium carbonate shells and skeletons. This may lead to population crashes in many species, including oysters, mussels, crabs and lobsters.\(^{17,18,19,20}\)
- Impacts on carbonate-dependent species like corals and pteropods could cause major ripple effects throughout ecosystems and food webs ultimately affecting even the largest animals in the oceans, as well as many commercial fisheries.\(^{22}\)
- Nearly 30 percent of the world’s tropical corals have vanished since 1980, mainly due to warming events. At the current rate of emission growth, tropical corals could be gone by the middle to the end of this century.\(^{23,24}\)
- If current emission trends continue, cold-water corals will be severely stressed by 2040, and two-thirds of them could be in a corrosive environment by the century’s end.\(^{25}\)
- The disappearance of coral reefs would cost society billions of dollars annually due to losses in fishing, tourism and coastal protection services.\(^{26}\)

\(^{421}\) Harrould-Kolieb and Savitz, *supra* note 418.

• Over 100 million people depend on coral reefs economically, and subsistence communities may experience health consequences and lack of food security due to the loss of protein associated with coral reefs.

• Many commercial fisheries depend on reefs which provide food and shelter for fish. The loss of reefs may further destabilize already depressed commercial fish populations.

• To protect coral reefs and the ecosystems that depend on them, we must stabilize carbon dioxide in the atmosphere at or below 350 ppm [parts per million]. To achieve this, global emissions must be reduced to 85 percent below 2000 levels by 2050, which will require industrialized nations to reduce their emissions 25 to 40 percent below 1990 levels by 2020 and 80 to 95 percent by 2050.

Ocean acidity has been rising at a geologically unprecedented rate. Currently, acidity is rising at least 100 times faster than at any other period during the last 100,000 years. A report issued by the Washington Shellfish Initiative Blue Ribbon Panel on Ocean Acidification noted in 2012 that:

Today, the ocean is acidifying at a rate nearly 10 times faster than the one that drove this extinction 55 million years ago, and the natural processes that ultimately will restore the oceanic pH [inverse measure of acidity] and carbonate chemistry balance cannot compensate rapidly enough, since full ocean circulation and dissolution of carbonate sediments require tens to hundreds of thousands of years to reach equilibrium.

Acidity matters, but also its rate of change is crucial. As the same report mentions:

Concentrations of atmospheric CO₂ have reached very high concentrations several times during the past 300 million years, and during a number of these periods, ocean pH was also lower than it is today (Hönisch et al., 2012). However, there was only one time over this entire period that the rate of pH change was even close to what our oceans are currently experiencing. [That was] during the Paleocene-Eocene Thermal Maximum, or PETM, some 55 million years ago . . . .

This rise in acidity resulted in an extinction event, during which “about half of benthic foraminifera (tiny shelled protists) species went extinct over a 1000-year period.”

From 1870 until 2006, atmospheric CO₂ changed about 1,000 times as fast as during the previous 400,000 years, and temperature changed 70 times as fast. As stated:

In addition to the absolute amount of change, the rate at which change occurs is critical to whether organisms and ecosystems will be able to adapt or accommodate to the new conditions . . . .
Given that recent and future rates of change dwarf even those of the ice age transitions, when biology at specific locations changed dramatically, it is likely that these changes will exceed the capacity of most organisms to adapt [emphasis added].

Coral reefs thrive in the top layer of the ocean, above the so-called calcite saturation horizon, a feature of the oceanic carbonate system.428 This top layer is thinning because of the acidification that comes with the increase in atmospheric CO\textsubscript{2}. The conclusion is that:429

If CO\textsubscript{2} emissions continue as projected over the rest of this century, the resulting changes in the marine carbonate system would mean that many coral reef systems in the Pacific would no longer be able to sustain a sufficiently high rate of calcification to maintain the viability of these ecosystems as a whole, and these changes perhaps could seriously impact the thousands of marine species that depend on them for survival.

A.6.26 Fourth National Climate Assessment chapter 14: perspectives on climate change mitigation

A.6.26.1 Key finding 1: comparing CO\textsubscript{2} with CH\textsubscript{4} and black carbon aerosols430 Reducing net emissions of CO\textsubscript{2} is necessary to limit near-term climate change and long-term warming. Other greenhouse gases (for example, methane) and black carbon aerosols exert stronger warming effects than CO\textsubscript{2} on a per ton basis,431 but they do not persist as long in the atmosphere; therefore, mitigation of non-CO\textsubscript{2} species contributes substantially to near-term cooling benefits but cannot be relied upon for ultimate stabilization goals. (Very high confidence)

A.6.26.2 Key finding 2: substantial global emissions reductions required before 2040, zero or negative subsequently Stabilizing global mean temperature to less than 3.6°F (2°C) above preindustrial levels requires substantial reductions in net global CO\textsubscript{2} emissions prior to 2040 relative to present-day values and likely requires net emissions to become zero or possibly negative later in the century. After accounting for the temperature effects of non-CO\textsubscript{2} species, cumulative global CO\textsubscript{2} emissions must stay below about 800 GtC in order to provide a two-thirds likelihood of preventing 3.6°F (2°C) of warming. Given estimated cumulative emissions since 1870, no more than approximately 230 GtC may be emitted in the future to remain under this temperature threshold. Assuming global emissions are equal to or greater than those consistent with the RCP4.5432 scenario, this cumulative carbon threshold would be exceeded in approximately two decades. (High confidence) [For a discussion of this key issue See section A.10, page 133.

428Harrould-Kolieb and Savitz, supra note 418, p. 10.
431Comparing CO\textsubscript{2} and CH\textsubscript{4} on a unit mass basis is misleading. Energy produced should be compared on a molar basis and as to global warming the relevant quantity is the molecular number density.
432Wayne, supra note 176.
A.6.26.3 Key finding 3: 2015 Paris Agreement

Achieving global greenhouse gas emissions reductions before 2030 consistent with targets and actions announced by governments in the lead up to the 2015 Paris climate conference would hold open the possibility of meeting the long-term temperature goal of limiting global warming to 3.6°F (2°C) above preindustrial levels, whereas there would be virtually no chance if net global emissions followed a pathway well above those implied by country announcements. Actions in the announcements are, by themselves, insufficient to meet a 3.6°F (2°C) goal; the likelihood of achieving that goal depends strongly on the magnitude of global emissions reductions after 2030. (High confidence) [This matter cannot be addressed in a scientifically sound way without re-assessing the global warming potential of methane, as discussed in section A.9, page 122; also see the Technical Appendix on page 150].

A.6.26.4 Key finding 4: climate intervention and geoengineering unproven at scale and unknown risk

Further assessments of the technical feasibilities, costs, risks, co-benefits, and governance challenges of climate intervention or geoengineering strategies, which are as yet unproven at scale, are a necessary step before judgments about the benefits and risks of these approaches can be made with high confidence. (High confidence)

A.6.27 Fourth National Climate Assessment chapter 15: potential surprises: compound extremes and tipping elements

A.6.27.1 Key finding 1: there are tipping points but instabilities cannot be quantified

Positive feedbacks (self-reinforcing cycles) within the climate system have the potential to accelerate human-induced climate change and even shift the Earth’s climate system, in part or in whole, into new states that are very different from those experienced in the recent past (for example, ones with greatly diminished ice sheets or different large-scale patterns of atmosphere or ocean circulation). Some feedbacks and potential state shifts can be modeled and quantified; others can be modeled or identified but not quantified; and some are probably still unknown. (Very high confidence in the potential for state shifts and in the incompleteness of knowledge about feedbacks and potential state shifts). [See section A.7, page 109.]

A.6.27.2 Key finding 2: simultaneous extreme events will have impacts larger than sum of parts

The physical and socioeconomic impacts of compound extreme events (such as simultaneous heat and drought, wildfires associated with hot and dry conditions, or flooding associated with high precipitation on top of snow or waterlogged ground) can be greater than the sum of the parts (very high confidence). Few analyses consider the spatial or temporal correlation between extreme events.

A.6.27.3 Key finding 3: modeling systematically underestimates risk of irreversible changes

While climate models incorporate important climate processes that can be well quantified, they do not include all of the processes that can contribute to feedbacks, compound extreme events, and abrupt and/or irreversible changes. For this reason, future

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435 Kopp et al., “Potential surprises—compound extremes and tipping elements,” supra note 337.
changes outside the range projected by climate models cannot be ruled out (very high confidence). Moreover, the systematic tendency of climate models to underestimate temperature change during warm paleoclimates suggests that climate models are more likely to underestimate than to overestimate the amount of long-term future change (medium confidence).

A.7 Surprises: state shifts, tipping points, and instabilities—additional details

A recurring theme in this Petition is the unpredictable nature of the timing of state shifts of the climate system; see page 18. Indeed, in the formulation of a recent intelligence report:

Research has not identified indicators of tipping points in climate-linked earth systems, suggesting a possibility of abrupt climate change.

A recent, 2018 study discusses in detail what possible climate systems trajectories resulting in a “Hothouse Earth” might look like and what are likely to be the pertinent timescales for tipping points (and domino-like cascades of such).

[W]e argue that social and technological trends and decisions occurring over the next decade or two could significantly influence the trajectory of the Earth System for tens to hundreds of thousands of years and potentially lead to conditions that resemble planetary states that were last seen several millions of years ago, conditions that would be inhospitable to current human societies and to many other contemporary species.

As the authors argue, the “impacts of a Hothouse Earth pathway on human societies would likely be massive, sometimes abrupt, and undoubtedly disruptive.”

The urgency and decadal timescale seem to have become a recurring theme in recent publications. Indeed, as a recent article in the Scientific American mentions:

The West Antarctic ice sheet is so voluminous that it will add more than 10 feet of sea-level rise alone if it catastrophically collapses. This scenario might only be avoided with extreme emissions cutbacks in the next decade, according to a June 2018 report in Nature.

Indeed, the abstract to which this refers ends with the statement: “Choices made in the next decade will determine what trajectory is realized.”

Many of the changes in the climate system reinforce themselves. For example, melting of Arctic sea ice changes the region’s albedo, i.e., its capacity to reflect solar radiation back into space, which reduce solar heating. However, as sea ice melts, it is replaced by ocean surface that absorbs a substantially larger fraction of that radiation, so that more sea ice melts. If the level of feedback exceeds a critical threshold, the process runs away, uncontrollably snowballing. As the Fourth National Climate Assessment puts it:


438Id., 6 of 8.


Positive feedbacks (self-reinforcing cycles) within the climate system have the potential to accelerate human-induced climate change and even shift the Earth’s climate system, in part or in whole, into new states that are very different from those experienced in the recent past (for example, ones with greatly diminished ice sheets or different large-scale patterns of atmosphere or ocean circulation). Some feedbacks and potential state shifts can be modeled and quantified; others can be modeled or identified but not quantified; and some are probably still unknown. (Very high confidence in the potential for state shifts and in the incompleteness of knowledge about feedbacks and potential state shifts).

One particular state shift might be caused by melting of methane hydrates, methane molecules locked up in a molecular “cell” of a dozen or so water molecules. Melting results in release of the “caged” methane. The threat this poses is summarized here:

Permafrost and methane hydrates contain large stores of methane and (for permafrost) carbon in the form of organic materials, mostly at northern high latitudes. With warming, this organic material can thaw, making previously frozen organic matter available for microbial decomposition, releasing CO$_2$ and methane to the atmosphere, providing additional radiative forcing and accelerating warming. This process defines the permafrost–carbon feedback. Combined data and modeling studies suggest that this feedback is very likely positive. This feedback was not included in recent IPCC projections but is an active area of research.

Fig. 19 reproduces Table 15.1 of the *Fourth National Climate Assessment*, which contains a list of tipping elements and among others mentions methane hydrates.

Model calculations, as is well-known among computational scientists, have a strong tendency to get stuck in metastable states, such as liquid water above the boiling point or below the freezing point. In such cases the modeling fails to show state shifts. It is therefore hardly surprising that even the best climate models suffer from the same problem. Indeed such models are known to underestimate the effect of run-away feedback loops.

While the distribution of climate model projections provides insight into the range of possible future changes, this range is limited by the fact that models do not include or fully represent all of the known processes and components of the Earth system (e.g., ice sheets or arctic carbon reservoirs), nor do they include all of the interactions between these components that contribute to the self-stabilizing and self-reinforcing cycles mentioned above (e.g., the dynamics of the interactions between ice sheets, the ocean, and the atmosphere). They also do not include currently unknown processes that may become increasingly relevant under increasingly large climate forcings. This limitation is emphasized by the systematic tendency of climate models to underestimate temperature change during warm paleoclimates [emphasis added] (section 15.5). Therefore, there is significant potential for humanity’s effect on the planet to result in unanticipated surprises and a broad consensus that the further and faster the Earth system is pushed towards warming, the greater the risk of such surprises.

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442 Wuebbles et al., *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, supra note 78, p. 95.
443 Id., p. 417.
444 For more details about feedback mechanisms in the climate system that could lead to “Hothouse Earth” see Table S2 in W. Steffen et al., “Trajectories of the Earth System in the Anthropocene—Supporting Information.” In: *Proceedings of the National Academy of Sciences* (Aug. 6, 2018). DOI: 10.1073/pnas.1810141115.
Figure 19: A list of tipping elements reproduced from the *Fourth National Climate Assessment*.

<table>
<thead>
<tr>
<th>Candidate Climatic Tipping Element</th>
<th>State Shift</th>
<th>Main Impact Pathways</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Atmosphere–ocean circulation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlantic meridional overturning</td>
<td>Major reduction in strength</td>
<td>Regional temperature and precipitation; global mean</td>
</tr>
<tr>
<td>circulation</td>
<td></td>
<td>temperature; regional sea level</td>
</tr>
<tr>
<td>El Niño–Southern Oscillation</td>
<td>Increase in amplitude</td>
<td>Regional temperature and precipitation</td>
</tr>
<tr>
<td>Equatorial atmospheric</td>
<td>Initiation</td>
<td>Cloud cover; climate sensitivity</td>
</tr>
<tr>
<td>superrotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional North Atlantic Ocean</td>
<td>Major reduction in strength</td>
<td>Regional temperature and precipitation</td>
</tr>
<tr>
<td>convection</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cryosphere</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antarctic Ice Sheet</td>
<td>Major decrease in ice volume</td>
<td>Sea level; albedo; freshwater forcing on ocean circulation</td>
</tr>
<tr>
<td>Arctic sea ice</td>
<td>Major decrease in summertime and/or</td>
<td>Regional temperature and precipitation; albedo</td>
</tr>
<tr>
<td>perennial area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenland Ice Sheet</td>
<td>Major decrease in ice volume</td>
<td>Sea level; albedo; freshwater forcing on ocean circulation</td>
</tr>
<tr>
<td><strong>Carbon cycle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methanehydrate</td>
<td>Massive release of carbon</td>
<td>Greenhouse gas emissions</td>
</tr>
<tr>
<td>Permafrost carbon</td>
<td>Massive release of carbon</td>
<td>Greenhouse gas emissions</td>
</tr>
<tr>
<td><strong>Ecosystem</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amazon rainforest</td>
<td>Dieback, transition to grasslands</td>
<td>Greenhouse gas emissions; biodiversity</td>
</tr>
<tr>
<td>Boreal forest</td>
<td>Dieback, transition to grasslands</td>
<td>Greenhouse gas emissions; albedo; biodiversity</td>
</tr>
<tr>
<td>Coral reefs</td>
<td>Die-off</td>
<td>Biodiversity</td>
</tr>
</tbody>
</table>
The Greenland Ice Sheet is particularly problematic in this respect:⁴⁴⁶

The flow of marine-terminating glaciers has been shown to be highly sensitive to changes in ocean temperature and circulation. Following a sufficiently large increase in submarine melt rate, a glacier can exhibit dynamic destabilization that triggers a rapid flow acceleration, thinning, or retreat until a new, dynamically stable geometric configuration is achieved . . . .

A brief prepared by the National Research Council based on an expert consensus report in 2013 called for an early warning system to help anticipate “abrupt changes in the physical climate system and steady changes in climate that can trigger abrupt changes:”⁴⁴⁷

This report summarizes the current state of knowledge on potential abrupt changes to the ocean, atmosphere, ecosystems, and high latitude areas, and identifies key research and monitoring needs. The report calls for action to develop an abrupt change early warning system to help anticipate future abrupt changes and reduce their impacts.

That the stability of ice sheets is not to be taken for granted is clear from the a recent study:⁴⁴⁸

The Greenland Ice Sheet (GIS) contains the equivalent of 7.4 meters of global sea-level rise . . . . Its stability in our warming climate is therefore a pressing concern. However, the sparse proxy evidence of the palaeo-stability of the GIS means that its history is controversial( . . . ). Here we show that Greenland was deglaciated for extended periods during the Pleistocene epoch (from 2.6 million years ago to 11,700 years ago), . . . . [Ellipses indicate omitted references.]

Such deglaciation events are not limited to the early history of the planet, which is clear from the titles of the following scientific studies:

1. _Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler Glaciers, West Antarctica, from 1992 to 2011;⁴⁴⁹_

2. _Marine ice sheet collapse potentially under way for the Thwaites Glacier Basin, West Antarctica.⁴⁵⁰_

The grounding line in this case is the line where a glacier leaves the ground and becomes an ice shelf. It is the line where sea water, ice, and land meet. Depending on the details of the topography, grounding lines can become highly unstable, leading to collapse.

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⁴⁴⁸J. Schaefer _et al._, “Greenland was nearly ice-free for extended periods during the Pleistocene.” In: 540 (2016), pp. 252–255. URL: http://dx.doi.org/10.1038/nature20146.


To conclude this overview we mention that Drijfhout et al. have put together a catalog of abrupt state shifts and mention:\textsuperscript{451}

Abrupt transitions of regional climate in response to the gradual rise in atmospheric greenhouse gas concentrations are notoriously difficult to foresee [emphasis added]. However, such events could be particularly challenging in view of the capacity required for society and ecosystems to adapt to them. We present, to our knowledge, the first systematic screening of the massive climate model ensemble informing the recent Intergovernmental Panel on Climate Change report, and reveal evidence of 37 forced regional abrupt changes in the ocean, sea ice, snow cover, permafrost, and terrestrial biosphere that arise after a certain global temperature increase. Eighteen out of 37 events occur for global warming levels of less than 2°C, a threshold sometimes presented as a safe limit [emphasis added].

A.7.1 Collapse of Atlantic Meridional Overturning Circulation

Stefan Rahmstorf, an ocean circulation expert of the Potsdam Institute for Climate Impact Research, wrote in a blog:\textsuperscript{452}

Blizzard Jonas [January 20–23, 2016] on the US east coast has just shattered snowfall records. Both weather forecasters and climate experts have linked the high snowfall amounts to the exceptionally warm sea surface temperatures off the east coast. In this post I will examine a related question: why are sea surface temperatures so high there . . . ?

I will argue that this warmth (as well as the cold blob in the subpolar Atlantic) is partly due to a slowdown of the Atlantic Meridional Overturning Circulation (AMOC) [aka the Gulf Stream System]

1. The warm sea surface temperatures are not just some short-term anomaly but are part of a long-term observed warming trend, in which ocean temperatures off the US east coast are warming faster than global average temperatures.

2. Climate models show a “cold blob” in the subpolar Atlantic as well as enhanced warming off the US east coast as a characteristic response pattern to a slowdown of the AMOC.

Confirming and adding to Rahmstorf’s post, a recent article in Nature has the following summary:\textsuperscript{453}

Evidence suggests that the circulation system of the North Atlantic Ocean is in a weakened state that is unprecedented in the past 1,600 years, but questions remain astowhenexactlytheydeclinecommenced.

\textsuperscript{451}Drijfhout et al., supra note 61.
Indeed, all of this is consistent with what previous studies\textsuperscript{454} have found, namely that “[t]he global conveyor has been weakening since the late 1930s and that the North Atlantic overturning cell suffered an abrupt shift around 1970.”\textsuperscript{455} We note the contradiction with the statement by the Intergovernmental Panel on Climate Change (IPCC) that “[t]here is no observational evidence of a trend in the Atlantic Meridional Overturning Circulation (AMOC).”\textsuperscript{456}

As the 2017, \textit{Fourth National Climate Assessment} states\textsuperscript{457} in the section that discusses potential surprises—see section A.6.27, page 108:

A decrease in AMOC [Atlantic Meridional Overturning Circulation] strength would accelerate sea level rise off the northeastern United States, while a full collapse could result in as much as approximately 1.6 feet (0.5 m) of regional sea level rise . . .

The following provides more details about this threat to the Rhode Island coastline:\textsuperscript{458}

The northward transport of warm waters makes places like the British Isles far balmier than similarly northerly locales, such as Newfoundland. It also transports important nutrients to major North Atlantic fisheries, and helps regulate sea levels along the East Coast of the U.S.

A slowdown in recent years led to a spike in sea levels along the U.S. coast and was linked by some researchers to unusually cold winter conditions in Europe. While that recent blip was attributed largely to natural variations in the current, a 2015 study found that recently the AMOC [Atlantic Meridional Overturning Circulation] has been slower than almost any time over the past 1,000 years.

Around a decade ago, “there was a lot of concern” about the potential for the AMOC to collapse completely, Delworth, who wasn’t involved in either study, said. This came from studies of sediment and ice cores that suggested the current had undergone wild changes in the past and had “induced large-scale changes around the planet.”

But climate models suggested only a weakening of the current in response to greenhouse gas-induced warming, at least over the next century, as summarized in the most recent iteration of the Intergovernmental Panel on Climate Change report.


\textsuperscript{456}IPCC, supra note 240, p. 8.

\textsuperscript{457}Kopp \textit{et al.}, “Potential surprises—compound extremes and tipping elements,” supra note 337, 15.4: Climatic Tipping Elements.

Those models, however, don’t factor in the fresh water pouring into the North Atlantic from the melt of the vast Greenland Ice Sheet.

Focusing attention on two recent papers addressing the Atlantic Meridional Overturning Circulation, this complex and fundamental system of ocean currents, including the wind-driven Gulf Stream, which is pivotal in the exchange of heat between the tropics and high latitudes, the prestigious scientific journal Nature in an editorial wrote:

Potential sharp changes in the circulation have been identified as a possible tipping point [emphasis added] in Earth’s physical systems. Since the 1950s, geologists and oceanographers have been gathering convincing evidence that alterations in ocean circulation are a key determinant of climate change.

Recent research confirms the perturbation of the North Atlantic circulation during the Eemian, the last time, about 120,000 years ago, when climate was warmer than today and sea levels exceeded the current ones by several meters, as discussed on page 58.

A.7.2 Latest bad news

The British Meteorological Office put out a press release on January, 31, of 2018 with the following “surprising” contents:

A new forecast published by scientists at the Met Office indicates the annual global average temperature is likely to exceed 1 °C and could reach 1.5°C above pre-industrial levels during the next five years (2018-2022).

There is also a small (around 10%) chance that at least one year in the period could exceed 1.5°C above pre-industrial levels (1850–1900), although it is not anticipated that it will happen this year. It is the first time that such high values have been highlighted within these forecasts.

Not that there ever was a credible justification for this, but until recently, policy makers and scientists talked about 2°C, as the global warming “guardrail” not to be passed. Since the Paris Agreement, this has been replaced by 1.5°C, once again without a solid, scientific basis, while raising serious questions of climate justice.

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Regarding distribution of impacts, the zone between a 1.5°C and 2°C warming reveals increasing aggregate risks from moderate to close to high. Again, danger and risk will be unevenly distributed, with higher risks and earlier impacts for socially marginalized groups, the elderly and children, and outdoor workers, as well as for people who may shift from transient to chronic states of poverty. This unevenness already affects millions under a 1.5°C increase, and likely many more under a 2°C warming, particularly in low-latitude and low- and middle-income countries.

Furthermore, as Hansen et al. have stressed for many years, arguments based on paleoclimate research strongly suggest that very little above a 1°C temperature increase can be reconciled with the precautionary principle—see the discussion centered around Fig. 12, on page 12. Indeed, more “surprises” are awaiting life one Earth.

As a final comment we add that the graph shown in Fig. 9 can be expanded, and in that case it would show that we reach 1.5°C in 2035 and and 2°C in 2045 if we continue business as usual.

A.8 War & peace—national security & geopolitics

A 2009 report by The Lancet and the University College London Institute for Global Health Commission provides the following enumeration of facts and dangers to support its conclusion that “[c]limate change is the biggest global health threat of the 21st century.”

Currently, a third of the world’s population lives within 60 miles of a shoreline and 13 of the world’s 20 largest cities are located on a coast. More than a billion people could be displaced in environmental mass migration. A stable coastline would not be re-established for hundreds of thousands of years. The north Atlantic ocean circulation (which includes the Gulf Stream circulation) could collapse plunging western Europe into a succession of severe winters followed by severe heatwaves during summer. An additional 2 billion people would be water stressed, while billions more would face hunger or starvation. The risk of armed conflict would rise. Public health systems around the world would be damaged, some to the point of collapse. Global biodiversity would be devastated.

Note that the “Gulf Stream circulation” is often used as a synonym for the Atlantic Meridional Overturning Circulation, discussed in section A.7.1, page 113. Its possible collapse will not only have an impact on Europe, it will lead to a redistribution of the water of the Atlantic Ocean giving rise to several feet of sea level rise in Rhode Island, the Ocean State. Global mass migration will lead to global insecurity, also directly affecting Rhode Island.

Indeed, the changing climate raises national and geopolitical security concerns. Retired members of the upper echelons of the U.S. Armed Forces list similar warnings in a report published by the Center for Naval Analyses. Among the main findings of the report is the following:

Projected climate change poses a serious threat to America’s national security.

[Original red, here and in other quotes from this source.]

\[\text{supra \ note 83, p. 1699.}\]
The predicted effects of climate change over the coming decades include extreme weather events, drought, flooding, sea level rise, retreating glaciers, habitat shifts, and the increased spread of life-threatening diseases. These conditions have the potential to disrupt our way of life and to force changes in the way we keep ourselves safe and secure.

Another finding of the same report reads:

*Climate change acts as a threat multiplier for instability in some of the most volatile regions of the world.*

Projected climate change will seriously exacerbate already marginal living standards in many Asian, African, and Middle Eastern nations, causing widespread political instability and the likelihood of failed states. Unlike most conventional security threats that involve a single entity acting in specific ways and points in time, climate change has the potential to result in multiple chronic conditions, occurring globally within the same time frame. Economic and environmental conditions in already fragile areas will further erode as food production declines, diseases increase, clean water becomes increasingly scarce, and large populations move in search of resources. Weakened and failing governments, with an already thin margin for survival, foster the conditions for internal conflicts, extremism, and movement toward increased authoritarianism and radical ideologies.

The 2007 report of these security experts accurately predicted what would take place around the Mediterranean. The Scientific American devoted to this area a special report entitled *Syria’s Climate Refugees* with as subtitle *Pushed out of their homeland by war and drought, Syrians seek a better future abroad.*[^467] Also the World Bank acknowledges that climate change has contributed to the conflicts in the Middle East and North Africa, listing outbreak of civil conflicts, expansion of terrorist organizations, escalation of environmental protests, deterioration of human security:[^468]

*Projected climate change will add to tensions even in stable regions of the world.* The U.S. and Europe may experience mounting pressure to accept large numbers of immigrant and refugee populations as drought increases and food production declines in Latin America and Africa.

Seven years after its first report, the same think tank issued a second report. In the foreword, Michael Chertoff, Former Secretary of Homeland Security, and Leon Panetta, Former Secretary of Defense, write: “The update makes clear that actions to build resilience against the projected impacts of climate change are required today. We no longer have the option to wait and see.”[^469]

The Military Advisory Board in its salutation to the reader writes:

At the end of the day, we validate the findings of our first report and find that in many cases the risks we identified are advancing noticeably faster than we anticipated [emphasis added]. We also find the world becoming more complex


in terms of the problems that plague its various regions. Yet thinking about how to manage the risks of projected climate change as just a regional problem or—worse yet—someone else’s problem may limit the ability to fully understand their consequences and cascading effects. We see more clearly now that while projected climate change should serve as catalyst for change and cooperation, it can also be a catalyst for conflict.

As the world’s population and living standards continue to grow, the projected climate impacts on the nexus of water, food, and energy security become more profound. Fresh water, food, and energy are inextricably linked, and the choices made over how these finite resources will be produced, distributed, and used will have increasing security implications.470

The water-food-energy “nexus” is illustrated Fig. 20.

Figure 20: Water, food, and fossil fuel energy are inextricable linked

The following enumeration of facts are from the same security experts report:471

- Asia has 15 of the world’s 20 largest cities, including Tokyo, Jakarta, Mumbai, and Dhaka, and most are on the coast or alongside low-lying deltas.

- Low-lying nations, such as Bangladesh, and entire island countries, such as the Maldives and Kiribati, face existential threats in the near term from sea level rise and devastating storm flooding.

470 supra note 469, p. 3.
471 Id., p. 15.
• Projected sea level rise will put critical regions at risk, including the entire Mekong Delta, eastern India, and Bangladesh, which combined produce the bulk of the region’s primary food staple, rice.

That sea level rise is an epic threat is clear from locations of the world’s megalopolises shown Fig. 21, which, once again, comes from the same security experts report.472

Figure 21: Burgeoning cities put enormous pressure on urban infrastructure—pressure that is only exacerbated by the effects of climate change, such as flooding.

The Department of Defense in its 2014 Quadrennial Defense Review identifies the effects of climate change as follows:473

Climate change may exacerbate water scarcity and lead to sharp increases in food costs. The pressures caused by climate change will influence resource competition while placing additional burdens on economies, societies, and governance institutions around the world. These effects are threat multipliers that will aggravate stressors abroad such as poverty, environmental degradation, political instability, and social tensions—conditions that can enable terrorist activity and other forms of violence.

National Security Implications of Climate-Related Risks and a Changing Climate474

DOD [Department of Defense] recognizes the reality of climate change and the significant risk it poses to U.S. interests globally. The National Security Strategy,

472 supra note 469, p. 15.
issued in February 2015, is clear that climate change is an urgent and growing threat to our national security, contributing to increased natural disasters, refugee flows, and conflicts over basic resources such as food and water. These impacts are already occurring, and the scope, scale, and intensity of these impacts are projected to increase over time.

Indeed, as stated in a report published in the prestigious medical journal The Lancet and as shown in Fig. 22, there is the generally recognized fact:

**The challenge of poverty and inequality**

Many of the most serious public health consequences of climate change will be experienced by the world’s poorest nations, increasing global health inequities.

Figure 22: **Density-equalizing cartogram**: Comparison of undepleted cumulative CO\textsubscript{2} emissions by country for 1950–2000 versus the regional distribution of four climate-sensitive health consequences (malaria, malnutrition, diarrhea, and inland flood-related fatalities).

Note also the following, bulleted items cited from the recent, peer-reviewed scientific literature:

\(\textsuperscript{475}\) supra note 83, p. 1703.

\(\textsuperscript{476}\) Id., p. 1712.
Deadly heat waves projected in the densely populated agricultural regions of South Asia—this will affect 20% of the world population:\textsuperscript{477}

The risk associated with any climate change impact reflects intensity of natural hazard and level of human vulnerability. Previous work has shown that a wet-bulb temperature of 35 °C can be considered an upper limit on human survivability. On the basis of an ensemble of high-resolution climate change simulations, we project that extremes of wet-bulb temperature in South Asia are likely to approach and, in a few locations, exceed this critical threshold by the late 21st century under the business-as-usual scenario of future greenhouse gas emissions. The most intense hazard from extreme future heat waves is concentrated around densely populated agricultural regions of the Ganges and Indus river basins. Climate change, without mitigation, presents a serious and unique risk in South Asia, a region inhabited by about one-fifth of the global human population, due to an unprecedented combination of severe natural hazard and acute vulnerability.

Global risk of deadly heat, currently affects 30% of of the world population:\textsuperscript{478}

Climate change can increase the risk of conditions that exceed human thermoregulatory capacity. Although numerous studies report increased mortality associated with extreme heat events, quantifying the global risk of heat-related mortality remains challenging due to a lack of comparable data on heat-related deaths. Here we conducted a global analysis of documented lethal heat events to identify the climatic conditions associated with human death and then quantified the current and projected occurrence of such deadly climatic conditions worldwide. We reviewed papers published between 1980 and 2014, and found 783 cases of excess human mortality associated with heat from 164 cities in 36 countries. Based on the climatic conditions of those lethal heat events, we identified a global threshold beyond which daily mean surface air temperature and relative humidity become deadly. Around 30% of the world’s population is currently exposed to climatic conditions exceeding this deadly threshold for at least 20 days a year. By 2100, this percentage is projected to increase to \textasciitilde 48% under a scenario with drastic reductions of greenhouse gas emissions and \textasciitilde 74% under a scenario of growing emissions. An increasing threat to human life from excess heat now seems almost inevitable, but will be greatly aggravated if greenhouse gases are not considerably reduced.

As we collect the insights of security experts and the scientific background for this and other chapters of this Petition, we are confronted with one of the essential features of exponential growth shown in Figs. 8 and 9: reality consistently outpaces projections—more about this in section A.11, page 138. As a consequence, the peer-reviewed, scientific climate literature expands at a rate that exceeds Petitioners’ ability to keep track of all latest developments.

\textsuperscript{477}Im, Pal, and Eltahir, supra note 303.

\textsuperscript{478}C. Mora \textit{et al.}, “Global risk of deadly heat.” In: \textit{Nature Climate Change} 7 (2017), pp. 501–506. doi: 10.1038/nclimate3322. URL: \url{http://dx.doi.org/10.1038/nclimate3322}. 
A.9 Methane’s global warming footprint and inventory problems

In 2011, Howarth, Santoro, and Ingraffea published a groundbreaking, peer-reviewed analysis of the greenhouse gas footprint of natural gas. The work earned Mark Ruffalo, Anthony Ingraffea, and Robert Howarth the Time magazine’s “People Who Mattered” award.

In his 2014 review of studies spurred by the 2011 publication, Howarth wrote:

"[T]he conclusion stands that both shale gas and conventional natural gas have a larger GHG [greenhouse gas footprint] than do coal or oil, for any possible use of natural gas and particularly for the primary uses of residential and commercial heating.

Subsequently, in his 2015 review Howarth wrote that “an estimated 12% of total production considered over the full life cycle from well to delivery to consumers” escapes. He ended the abstract of this paper stating:

"[T]he total greenhouse gas emissions from fossil fuel use in the USA rose between 2009 and 2013, despite the decrease in carbon dioxide emissions. Given the projections for continued expansion of shale gas production, this trend of increasing greenhouse gas emissions from fossil fuels is predicted to continue through 2040.

Note that the stark contrast with the quote from on page 131 from the United States 2014 Climate Action Report, discussed in detail in section A.9.4.

What follows is a review of some of the results of research that was prompted by the work of Howarth et al. One of the issues that this section does not cover in detail is exemplified by a recent study brought about by the natural gas leak from the Aliso Canyon storage facility, near Los Angeles, California from October 2015 to February 2016, “the largest single accidental release of greenhouse gases in US history.” A 2017 review of more than 14,000 active underground storage U.S. facilities revealed “numerous reporting inconsistencies” and concluded that:

This national baseline assessment identifies regulatory data uncertainties, highlights a potentially widespread vulnerability of the natural gas supply chain [emphasis added], and can aid in prioritization and oversight for high-risk wells and facilities.

Once again, the contrast with the quote on page 131 from the 2014 Climate Action Report of the United States Department of State is striking.
A.9.1 The pivotal role of natural gas (methane)

The Energy Information Administration characterizes Rhode Island energy consumption in 2016, a representative year, as follows:\textsuperscript{484}

1. Rhode Island Natural gas fueled almost 96\% of Rhode Island’s net electricity generation in 2016.

2. Rhode Island’s total emissions of carbon dioxide are the second-lowest among all states.

The second item is correct, but from a global climate change perspective it obscures the \textit{carbon leakage} issue associated with the full methane life-cycle, mentioned in section 3, page \textsuperscript{29}.

As explained in detail in the Technical Appendix—see Tab. I of section B, page 150—if 0.76\% of natural gas escapes unburned it is worse for global warming than oil. For coal this critical threshold is 2.2\%.\textsuperscript{485} The energy policy of the State of Rhode Island takes none of this into account, as demonstrated by the statements made by the Rhode Island Office of Energy Resources and Governor Raimondo quoted in section A.1, page 28.

A.9.2 Natural gas: a chronology in brief

The Environmental Protection Agency has a long history of underestimating the amount of methane (CH\textsubscript{4}) that escapes into the atmosphere unburned, aka \textit{fugitive methane}. The following is a review this burning problem, which among others has resulted, as mentioned, in a highly questionable report submitted by the U.S. Department of State in 2014 to fulfill its obligations under the United Nations Framework Convention on Climate Change.\textsuperscript{486} (For more details see section A.9.4, page 130.)

The following review of the some of the impacts of fugitive methane is based on a compendium about fracked gas and its health impacts put together by the Concerned Health Professionals of New York and Physicians for Social Responsibility:\textsuperscript{487,488}

1. This is from the \textit{Foreword to the Fourth Edition} of the compendium:\textsuperscript{489}

   [T]he United States, which ratified the Paris Agreement on September 3, 2016, has pledged to reduce its greenhouse gas emissions 26–28 percent by 2025, as compared to 2005 levels. Research published last September shows

\begin{footnotesize}
\begin{itemize}
\item \textsuperscript{484} supra note 72.
\item \textsuperscript{485} Nightingale, supra note 33.
\item \textsuperscript{486} supra note 346, p. 11.
\item \textsuperscript{489} Bushkin-Bedient \textit{et al.}, \textit{Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (Unconventional Gas and Oil Extraction)—4th edition}, supra note 487, p. 3.
\end{itemize}
\end{footnotesize}
that our nation is on track to miss this target, in large part because of increasing emissions of methane, which is a powerful heat-trapping gas. As documented in a new federal inventory of greenhouse gases, methane leaks from U.S. oil and gas operations are higher than previously estimated, as are total U.S. methane emissions, which increased by more than 30 percent between 2002 and 2014. Indeed, as revealed by both satellite and ground observations, our nation’s methane emissions are responsible for 30–60 percent of the recent upsurge in global atmospheric methane concentrations. (See footnotes 492 and 493). Most of this excess methane, as is revealed by a study published in September 2016 in the Proceedings of the National Academy of Sciences, represents fugitive emissions from U.S. oil and gas operations. These and other emerging data, described further in the pages that follow, indicate that fracking, an enabler of these trends, is incompatible with climate stability and the goal of rapid decarbonization that it requires. [Omitted footnotes are indicated by ellipses; original references were replaced by references to the same sources.]

2. This is a partial summary of threats to the climate system posed by methane:

Methane is a powerful greenhouse gas. An increasing number of studies reveal high levels of methane leaks from gas drilling, fracking, storage, and transportation, undermining the notion that natural gas is a climate solution or a transition fuel. These studies contradict inventories prepared by the U.S. Environmental Protection Agency (EPA), which, through early 2016, continued to underestimate the impacts of methane and natural gas drilling on the climate. In April 2016, the EPA raised methane emissions estimates for oil and natural gas operations by 34 percent, retroactively increased estimates of past methane losses, and named the oil and gas industry as the single leading source of methane emissions to the atmosphere. Multiple lines of evidence point to the central role of unconventional oil and gas extraction as the driver

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496 Bushkin-Bedient et al., Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (Unconventional Gas and Oil Extraction)—4th edition, supra note 487, p. 137.
of recent increases in global greenhouse gases, especially methane. These include the atmospheric pattern of increased methane concentrations directly over intensively fracked areas of the United States; sharp upticks in global methane and co-occurring ethane levels that correspond to the onset of the U.S. fracking boom; and documentation of catastrophic amounts of methane released from storage facilities and other “super-emitting” sites. An influential 2013 study that reported low rates of methane leakage from oil and gas operations was revealed to have relied on flawed instrumentation that can underestimate methane loss. Further, the widely touted claim that the U.S. fracking boom has helped drive recent declines in carbon dioxide emissions in the United States has been upended by research showing that almost all of the CO$_2$ emission reductions between 2007 and 2009 were the result of economic recession rather than coal-to-gas fuel switching, as was previously presumed. Other lines of research suggest the extremely important role that technological innovations related to energy efficiency can play in reducing reliance on fossil fuels and speeding a transition to renewable energy sources. Drilling, fracking, and expanded use of natural gas threaten not only to exacerbate climate change but also to stifle investments in, and expansion of, renewable energy [original emphasis].

- July 11, 2016—A group of 130 environmental and health organizations signed a formal complaint with the Inspector General of the EPA that assailed a pivotal 2013 study published in the Proceedings of the National Academies of Sciences and led by University of Texas chemist David T. Allen. The letter accused Allen of “systemic fraud, waste, and abuse” for his reliance on an inaccurate measurement device that was known to underestimate methane levels. Partially funded by the oil industry, Allen’s study reported very low methane emission rates as part of a large survey of 190 drilling and fracking sites across the nation. That flawed study was influential, said complainants, in preventing EPA from recognizing the magnitude of methane leakage from drilling and fracking operations.\textsuperscript{497} (See also the entry below for March 24, 2015.)\textsuperscript{498}

- May 25, 2016—As part of the first field study to directly measure methane emissions from the heavily drilled Bakken Shale formation in northwestern North Dakota, a team led by atmospheric chemist Jeff Peischl at the National Oceanic and Atmospheric Administration (NOAA) flew research aircraft over the region in May 2014. The researchers derived a methane emission rate of 275,000 tons of methane per year, which is similar to the rate of methane leakage in the Front Range area of Colorado but significantly lower than previous studies of the Bakken area that relied on satellite remote sensing data during an earlier time period.


\textsuperscript{498} This entry documents problems with EPA approved equipment yielding serious underestimates of methane emissions; see \textit{Id.}, p. 145.
A SCIENTIFIC BACKGROUND—DETAILS

(2006–2011). Analyzing the chemical composition of air samples, the NOAA team determined that almost all of the methane originated with oil and gas operations, rather than with natural or agricultural sources, and estimated a leakage rate of 4.2–8.4 percent.\(^499\) Scaled to production, this emission rate is slightly lower than that estimated by U.S. Environmental Protection Agency (EPA) in its recently revised inventory.\(^500\) In an accompanying news release, the agency said, “Data on oil and gas show that methane emissions from the sector are higher than previously estimated. The oil and gas sector is the largest emitting-sector for methane and accounts for a third of total U.S. methane emissions.” … Past EPA inventories had identified livestock as the number one source of U.S. methane. These annual inventories fulfill the EPA’s obligations under the United Nations Framework Convention on Climate Change, signed and ratified by the United States in 1992, and attempt to identify and quantify U.S. anthropogenic sources and sinks of greenhouse gases for the time period 1990 and forward. The upward revision in both past and current inventories is a reflection of changing methodologies for measuring methane leaks.\(^503\) Older methods included the incorporation of “bottom-up” data supplied by the oil and gas industry, without attention to high-emitting or super-emitting sources or possible sources of error introduced by flawed measuring equipment. In addition, the use of a Global Warming Potential multiplier of 25 for methane, which is based on a 100-year time horizon, rather than 86 for a 20-year time horizon, has come under sustained criticism given the urgency of the climate crisis.\(^504,505\)


\(^{501}\) supra note 491.


\(^{505}\) Profeta, supra note 169.
April 7, 2016—Since 2009, corresponding to the advent of the U.S. shale gas boom, North American ethane emissions have increased by 5 percent per year. This trend represents a reversal of a previous multi-decade decline (mid-1980s until the end of the 2000s) in the abundance of atmospheric ethane that had been attributed to the reduction of fugitive emissions from fossil fuel sources. These are the findings of an international research team, which analyzed remote sensing data gathered by the Network for the Detection of Atmospheric Composition Change at globally distributed ground-based sites. Ethane is a volatile organic compound (VOC) that readily reacts with nitrogen oxides in the presence of sunlight to create ground-level ozone (smog). Also a potent greenhouse gas, ethane is co-released along with methane from drilling and fracking sites. The source of two-thirds of the ethane in Earth’s atmosphere is leakage from natural gas wells and pipelines. Because ethane is co-emitted with methane and can serve as a marker for it, this documentation of a sharp, recent uptick in atmospheric ethane is part of a larger body of evidence suggesting that U.S. drilling and fracking operations are driving up global methane levels.  

The compendium has more information, but the above excerpts should suffice.

A.9.3 Peer-reviewed literature

The following enumeration contains quotes is from peer-reviewed, scientific papers each of which addresses underestimates by the Environmental Protection Agency of fugitive methane.

1. The concluding section of a scientific paper reporting on methane emissions from the Bakken shale region in North Dakota states:  

   This is approximately a factor of 1.4–2.3 greater than the 2013 EPA GHG inventory emission rate from petroleum systems when scaled by oil production. Stated in terms of the natural gas extracted from the ground, we estimate atmospheric loss rates from natural gas production of 4.2–8.4%, similar to the rate found for the Denver-Julesburg oil-producing region [Pétron et al., 2014].

   We note once again that fugitive CH$_4$ in excess of 2.2% makes natural gas a more serious problem for the climate than coal; the critical threshold for oil is 0.76%. (See Tab. 1 of section B.) The final, published version of the paper contains this:

   **Note Added in Proof**
   The EPA GHG inventory report for 2014 was released in April 2016 (EPA 430-R-16-002, follow this link), while this paper was under final review; inventoried emissions from petroleum systems increased by a factor of 2.5 compared to the GHG inventory for 2013 that was used for comparison above. The CH$_4$ emissions attributed to oil and gas operations in this paper are

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507Peischl et al., *supra* note 499, p. 6110.
now a factor of 0.51–0.85 times the 2014 EPA GHG inventory for petroleum systems scaled by oil production in the Bakken.

2. A satellite study by Turner et al. revealed that.\textsuperscript{508,509}

Here we use satellite retrievals and surface observations of atmospheric methane to suggest that U.S. methane emissions have increased by more than 30% over the 2002–2014 period.

A subsequent study attributed these increases to fossil fuel sources.\textsuperscript{510} Once again we note that this result clearly invalidates data contained in the United States Climate Action Report 2014 of the United States Department of State.\textsuperscript{511} (For further details see section A.9.4, page 130.)

3. Super-emitting sites, as mentioned above, were found in the Four Corners region.\textsuperscript{512}

Our analysis detected more than 250 individual methane plumes from fossil fuel harvesting, processing, and distributing infrastructures, spanning an emission range from the detection limit $\sim 2$ kg/h to 5 kg/h through $\sim5,000$ kg/h. Observed sources include gas processing facilities, storage tanks, pipeline leaks, and well pads, as well as a coal mine venting shaft. Overall, plume enhancements and inferred fluxes follow a lognormal distribution, with the top 10% emitters contributing 49 to 66% to the inferred total point source flux . . . .

4. A study of natural-gas-fired power plants revealed that the problem occurs not only at the up-stream side of pipelines, but also downstream at the user side. Once again, there are the ubiquitous, significant underestimates of fugitive CH$_4$ by the Environmental Protection Agency.\textsuperscript{513}

A new peer-reviewed paper in Environmental Science and Technology\textsuperscript{514} suggests that methane emissions from natural gas power plants and oil refineries may be significantly higher than accounted for in current inventories. The report estimates average hourly methane emissions 11 to 90 times higher for refineries, and 21 to 120 times higher for natural gas power plants than

\textsuperscript{508}Turner et al., supra note 492.
\textsuperscript{509}Magill, supra note 493.
\textsuperscript{510}J. R. Worden et al., “Reduced biomass burning emissions reconcile conflicting estimates of the post-2006 atmospheric methane budget.” In: Nature Communications 8 (2017), pp. 1–11. DOI: 10.1038/s41467-017-02246-0.
\textsuperscript{511}supra note 346, p. 11.
\textsuperscript{513}J. Rudek and D. Lyon, Study: Emissions from power plants, refineries may be far higher than reported. Environmental Defense Fund. 2017. URL: http://blogs.edf.org/energyexchange/2017/03/16/study-emissions-from-power-plants-refineries-may-be-far-higher-than-reported/ (visited on Dec. 29, 2017).
\textsuperscript{514}T. N. Lavoie et al., “Assessing the Methane Emissions from Natural Gas-Fired Power Plants and Oil Refineries.” In: Environmental Science & Technology 51.6 (2017), pp. 3373–3381. DOI: 10.1021/acs.est.6b05531. eprint: http://dx.doi.org/10.1021/acs.est.6b05531. URL: http://pubs.acs.org/doi/pdfplus/10.1021/acs.est.6b05531.
those calculated from data provided by facility operators to Environmental Protection Agency’s Greenhouse Gas Reporting Program.

By multiplying total CO\textsubscript{2} emitted annually by all US natural gas power plants and refineries (as tallied by EPA) by the methane-to-CO\textsubscript{2} emission ratio determined in the study, the authors estimate yearly methane emissions from the nation’s refineries and gas-fired power plants are twenty times higher than currently reported [emphasis added].

In the concluding section of the paper, the authors mention that average CH\textsubscript{4} emission rates were larger than facility-reported estimates by factors of 21–120 for natural gas-fired power plants and 11–90 for refineries.\(^{515}\) Additionally, as the abstract mentions, calculated throughput-based emission factors derived from natural gas-fired power plants measurements made in this study were, on average, a factor of 4.4 (stacks) and 42 (facility-scale) larger than industry-used emission factors.\(^{516}\)

As the peer-reviewed paper states:\(^{517}\)

Recent studies indicate that CH\textsubscript{4} leakage into the atmosphere may negate its advantages, for instance, a loss rate of 1.5% from natural gas production processes would increase the 20 year climate impact of natural gas by 50%.

5. Not only is CH\textsubscript{4} a potent greenhouse gas, it can be transported by groundwater over unexpectedly large distances, so that it easily escapes the standard methods of detection.\(^{518}\)

Our findings demonstrate that even small-volume releases of methane gas can cause extensive and persistent free phase and solute plumes emanating from leaks that are detectable only by contaminant hydrogeology monitoring at high resolution.

6. A study of methane emissions from the natural infrastructure of the urban Boston region finds:\(^{519}\)

This study quantifies the full seasonal cycle of methane emissions and the fractional contribution of natural gas for the urbanized region centered on Boston. Emissions from natural gas are found to be two to three times larger [emphasis added] than predicted by existing inventory methodologies and industry reports.

7. Also methane emissions inventories for Southern California South Coast Air Basin (SoCAB) have produced underestimates.\(^{520}\)

\(^{515}\)Lavoie \textit{et al.}, supra note 514, p. 3373.

\(^{516}\)Id., p. 3373.

\(^{517}\)Id., p. 3373.

\(^{518}\)A. G. Cahill \textit{et al.}, “Mobility and persistence of methane in groundwater in a controlled-release field-experiment.” In: \textit{Nature Geoscience} 10 (2017), pp. 289–294. DOI: 10.1038/ngeo2919. URL: \url{http://dx.doi.org/10.1038/ngeo2919}.


\(^{520}\)D. Wunch \textit{et al.}, “Quantifying the loss of processed natural gas within California’s South Coast Air Basin using long-term measurements of ethane and methane.” In: \textit{Atmospheric Chemistry and Physics}
8. A recent news item entitled *Methane leaks from US gas fields dwarf government estimates* in Nature reports:521

The analysis,522 published on 21 June in Science, is one of the most comprehensive looks yet at methane output from US oil and gas production, and reinforces previous studies that suggested emissions outpaced government estimates. That research prompted the US government to develop regulations that would restrict methane emissions from oil and gas production—rules that US President Donald Trump is now attempting to roll back.

The analysis concluded that methane emissions in 2015 were about 60% greater than estimates from the Environmental Protection Agency’s greenhouse gas inventory: a 2.3% leakage rate compared to the 1.4% the federal agency’s estimate.

A.9.4 Crucial reporting and measurement matters

In addition to pervasive, persistent flaws in the methane inventory of the Environmental Protection Agency, there is a serious problem with the accounting system itself. To be specific, the issue is the method used to convert a mixture of CO\textsubscript{2} and non-CO\textsubscript{2} greenhouse gases to a so-called CARBON DIOXIDE EQUIVALENT, the “common currency” used to express the effect of a mixture of different greenhouse gases in terms of a single, universal unit of measurement. Obviously, an inaccurate “exchange rate” produces inaccurate results.

A group of 21 highly respected Ph.D. scientists addressed exactly this matter in a letter523—dated July 29, 2014—to top officials of the Obama administration.524

We write to recommend that you take several actions to ensure that the strong, near-term warming influence of methane emissions be accurately measured, reported, and addressed in the Administration’s program to slow global warming. To assist with the development and implementation of urgently needed methane reductions — particularly in the oil and gas industry, the agricultural sector, landfills and coal mining — the most current and relevant information possible regarding the very important contributions of methane emissions to near- and long-term global climate change must be available to and used by policy-makers.

Accurate representation of methane’s warming influence on the climate is important not only because methane’s warming influence over the 21st century makes


524The officials were: John Holdren, Director Office of Science and Technology Policy, Michael Boots, Acting Chair Council on Environmental Quality, Ernest Moniz, Secretary Department of Energy, Gina McCarthy, Administrator Environmental Protection Agency, and Dan Utech, Director for Energy and Climate Change.
it the second most important anthropogenic greenhouse gas (with a current radiative forcing of 1 watt per square meter compared to 1.7 for CO$_2$), but also — at least as importantly — because the climate system responds more quickly to methane with its short residence time in the atmosphere than to CO$_2$, where climate lags are quite long. This difference means that aggressive mitigation of methane emissions is essential if the near-term pace of climate change is to be slowed. Such a slowing is essential to increase the likelihood of avoiding climatic tipping points and to moderate the intensification of current climate impacts, including Arctic sea-ice loss (which has also been implicated in intensifying extreme weather anomalies), ice sheet melt, permafrost thawing, and declining seasonal snowpack.

Both the reporting issues and the scientific findings discussed in this section raise serious questions about statements contained in the 2014 United States Climate Action Report of the United States Department of State such as:

**Methane Emissions**

CH$_4$ emissions decreased by 1.1 percent [emphasis added] since 2005, primarily resulting from the following sources: natural gas systems, enteric fermentation associated with domestic livestock, and decomposition of wastes in landfills. Emissions from natural gas systems, the largest anthropogenic source of CH$_4$ emissions, have decreased by 9 percent since 2005, due largely to a decrease in emissions from field production.

The report states in a footnote that:

Unless otherwise stated, all GHGs [greenhouse gases] in this document are reported in teragrams [metric megaton] of CO$_2$ equivalents (Tg CO$_2$e), using the 100-year global warming potentials (GWPs) listed in the IPCC’s Second Assessment Report (SAR) (IPCC 1996) to convert non-CO$_2$ gases to CO$_2$e. UNFCCC guidelines for inventories and national communications require that emissions be reported using SAR GWP values.

Why the information contained in the United States Department of State report is misleading is further discussed in the Technical Appendix, page 150; technical terms are defined elsewhere; see (ACRONYM) GLOBAL WARMING POTENTIAL (GWP) and CARBON DIOXIDE EQUIVALENT.

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525The following is from footnote 1 in the letter: “IPCC, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, SUMMARY FOR POLICYMAKERS at Figure SPM.5, page 12 (2013). The cited radiative forcing of 1 W/m$^2$ for methane includes feedbacks; the concentration-based estimate of methane’s forcing is 0.48 W/m$^2$.”


527* supra* note 346, p. 11.

528Footnote 6 of *Id.*, p. 20.

529Also see Nightingale, * supra* note 33.
The Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) lists as the global warming potential of methane with a 100-year time horizon a value of 21.530,531 This is to be compared with 120, the instantaneous value of the global warming potential of methane.532,533 We also note that the Intergovernmental Panel on Climate Change (IPCC) currently lists 34 as the global warming potential of methane.534

In sections A.10, page 133, and A.10.2, page 136, we discuss this issue in detail. Here we mention only the conclusion: the effect of using an outdated value for the global warming potential and a time-horizon of 100 years, which has no scientific justification whatsoever, is that the impact of methane on global warming is underestimated by at least a factor of five. Indeed the global warming potential plays exactly the same role as the exchange rate for foreign valuta, which is one of the reasons for the aptness of the term accounting trick, used on page 133 in the context of the support of the Rhode Island Office of Energy Resources for Invenergy LLC’s power plant planned in Burrillville.

Both the flaws in the greenhouse gas inventory and the global warming potential “exchange rate” shed serious doubt on the validity on the historical and projected energy sector emission numbers contained in the United States Climate Action Report 2014. In Tab. 4 we reproduce those numbers, which even at face value are disastrous for the climate system, but in fact are considerable underestimates of the greenhouse gas emissions.535

Table 4: Historical and projected greenhouse gas emissions as reported in the United States Department of State 2014 Climate Action Report for the energy sector (Tg CO₂-e).

<table>
<thead>
<tr>
<th>Historical</th>
<th>Projected</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,258 4,321 4,104 3,981</td>
<td>3,936 4,038 4,141 4,207</td>
</tr>
</tbody>
</table>

The same global warming potential “exchange rate” issue invalidates the statement made by the Rhode Island Office of Energy Resources in its advisory opinion in support of the Clear River Energy Center proposed by Invenergy LLC for Burrillville, Rhode Island. The claim that the “negative values indicate a net reduction in emissions with the Project in service” lacks scientific support, when the goal is to avoid danger to the global climate system.536 Presumably, the technical staff who put together the numbers in Tab. 5 knew what they were doing, but Petitioners question whether the people Rhode Island understand

530Table 4 of Houghton et al., supra note 45, p. 22.
532See Fig. 8.29, Tables 8.7 and 8.A.1 Stocker et al., Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, supra note 34, pp. 712,714,731.
533section 8.SM.11 Myhre et al., supra note 47, p. 8SM-14.
534Table 8.7, Stocker et al., Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, supra note 34, p. 714.
535From Table 3 supra note 346, p. 18.
the nature of the “accounting trick” covered up by the meaningless, purportedly four-figure accurate numbers displayed in the table. “Policy-makers often treat a GWP as a value-neutral measure, but the time-scale choice is central to achieving specific objectives . . . .”

Petitioners have not been able to identify any indication that technical staff and the policy makers at Rhode Island Office of Energy Resources are taking the implied trade-offs into account.

Table 5: Impact of CREC on total emissions reductions on ISO-NE/NYISO footprint.

<table>
<thead>
<tr>
<th></th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Emission Change (thousand short tons)</td>
<td>-783</td>
<td>-1,233</td>
<td>-1,122</td>
<td>-1,011</td>
<td>-998</td>
<td>-985</td>
<td>-1,002</td>
</tr>
</tbody>
</table>

We also mention that the *Rhode Island Greenhouse Gas Emissions Reduction Plan* of 2016 contains estimates of Rhode Island greenhouse gas sources based on poorly defined emission totals, because no global warming potential “exchange rates” are specified. We return to this crucial issue in section A.10, page 133.

Indeed, Brown professor Timmons Roberts in his expert testimony about the power plant that Invenergy LLC plans to build in Burrillville recently stated that:

OER [Office of Energy Resources] is essentially using an accounting trick to pretend that building a large, new, long-lived fossil-fuel power plant in Rhode Island will actually result in Rhode Island being able to meet its targets under the Resilient Rhode Island Act.

Finally we note that problems with natural gas reporting are not confined to the United States. Columbia’s Oil and Gas Commission, a Canadian regulator, has withheld information about gas leakage from the public.

### A.10 Global emissions budget

In this section we discuss the rationale behind the *GLOBAL EMISSIONS BUDGET*. First, we address the simple part of this, namely that place and time of emission of CO₂ have negligible impact on global warming. All that matters in the case of CO₂ is the cumulative total emitted since the Industrial Revolution.

The effect of CH₄ is more complicated and discussed in section A.10.2. The decay of CH₄ in the atmosphere is an essential feature, obscured by the widespread use of the GWP concept with its hidden variable, the TIME HORIZON.

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538Figure 1 in the plan is an example on and also footnote 2 are clear examples of patently inaccurate definitions in supra note 112, p. 8.


A.10.1 Irrelevance of time and place of emissions

As Matthews et al. found for CO$_2$ emissions, “the total allowable emissions for climate stabilization do not depend on the timing of those emissions . . . .” Carbon-climate response is “approximately constant with respect to time and emissions scenario.” Hansen et al. echo this: “eventual warming depends on cumulative carbon emissions, not on the temporal history of emissions” and went on to propose a GLOBAL EMISSIONS BUDGET based on this. The details are contained in a lengthy, thoroughly sourced paper of which the following is the abstract.

We assess climate impacts of global warming using ongoing observations and paleoclimate data. We use Earth’s measured energy imbalance, paleoclimate data, and simple representations of the global carbon cycle and temperature to define emission reductions needed to stabilize climate and avoid potentially disastrous impacts on today’s young people, future generations, and nature. A cumulative industrial-era limit of $\sim 500$ GtC fossil fuel emissions and $100$ GtC storage in the biosphere and soil would keep climate close to the Holocene range to which humanity and other species are adapted. Cumulative emissions of $\sim 1000$ GtC, sometimes associated with $2^\circ$C global warming, would spur “slow” feedbacks and eventual warming of $3-4^\circ$C with disastrous consequences. Rapid emissions reduction is required to restore Earth’s energy balance and avoid ocean heat uptake that would practically guarantee irreversible effects. Continuation of high fossil fuel emissions, given current knowledge of the consequences, would be an act of extraordinary witting intergenerational injustice. Responsible policymaking requires a rising price on carbon emissions that would preclude emissions from most remaining coal and unconventional fossil fuels and phase down emissions from conventional fossil fuels.

Fig. 23 is from this same paper and shows the time-evolution of a instantaneous pulse of CO$_2$ in the atmosphere and how long it takes for the atmospheric CO$_2$ concentration to return to 350 parts per million, the level deemed safe by Hansen et al., if the danger of non-CO$_2$ climate forcings is ignored. These plots show how difficult return it to 350 parts per million if emissions continue to grow according to business as usual for even a few decades.

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542 Id., p. 830.
543 Hansen et al., “Assessing ‘dangerous climate change’: required reduction of carbon emissions to protect young people, future generations and nature.,” supra note 9, p. 2.
544 Id.
Global temperature is a fundamental climate metric highly correlated with sea level, which implies that keeping shorelines near their present location requires keeping global temperature within or close to its preindustrial Holocene range. However, global temperature excluding short-term variability now exceeds +1 °C relative to the 1880–1920 mean and annual 2016 global temperature was almost +1.3 °C. We show that global temperature has risen well out of the Holocene range and Earth is now as warm as it was during the prior (Eemian) interglacial period, when sea level reached 6–9 m [meters] higher than today. Further, Earth is out of energy balance with present atmospheric composition, implying that more warming is in the pipeline, and we show that the growth rate of greenhouse gas climate forcing has accelerated markedly in the past decade. The rapidity of ice sheet and sea level response to global temperature is difficult to predict, but is dependent on the magnitude of warming. Targets for limiting global warming thus, at minimum, should aim to avoid leaving global temperature at Eemian or higher levels for centuries. Such targets now require negative emissions, i.e., extraction of CO₂ from the air. If phasedown of fossil fuel emissions begins soon, improved agricultural and forestry practices, including reforestation and steps to improve soil fertility and increase its carbon content, may provide much of the necessary CO₂ extraction. In that case, the magnitude and duration of global temperature excursion above the natural range of the current interglacial (Holocene) could be limited and irreversible climate impacts could be minimized.

In contrast, continued high fossil fuel emissions today place a burden on young people to undertake massive technological CO₂ extraction if they are to limit climate change and its consequences. Proposed methods of extraction such as bioenergy with carbon capture and storage (BECCS) or air capture of CO₂ have minimal estimated costs of USD 89–535 trillion this century and also have large

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546Hansen et al., “Young people’s burden: requirement of negative CO₂ emissions,” supra note 37.
risks and uncertain feasibility. *Continued high fossil fuel emissions unarguably sentences young people to either a massive, implausible cleanup or growing deleterious climate impacts or both* [emphasis added].

We discussed stabilizing the climate in section A.1, page 26, in terms of the need to reduce the atmospheric CO$_2$ density to 350 parts per million from its current value, which oscillates around 410 parts per million at the Mauna Loa Observatory.\(^{547}\)

### A.10.2 Choice of time horizon

Meaningful, fair\(^{548}\) and honest greenhouse gas emissions accounting is required to address pivotal issues associated with energy supply, transport, buildings, industry, agriculture, forestry, and waste management.\(^{549}\)

The choice of the time horizon used in the conversion of greenhouse gas impacts to a CARBON DIOXIDE EQUIVALENT “common currency” of has a profound impact on policy. As we mentioned several times before, choosing an unfounded “exchange rate,” too low by a factor of more than four, is one of the accounting tricks used in the United States in general and in Rhode Island in particular to obscure the greenhouse gas footprint of natural gas.

Indeed, as the Intergovernmental Panel on Climate Change (IPCC) comments in its most recent assessment:\(^{550}\)

> The choice of **TIME HORIZON** has a strong effect on the GWP [global warming potential] values—and thus also on the calculated contributions of CO$_2$-equivalent emissions by component, sector or nation. There is no scientific argument for selecting 100 years compared with other choices . . . . The choice of **TIME HORIZON** is a value judgement because it depends on the relative weight assigned to effects at different times.

More in detail the the assessment explains:\(^{551}\)

> Emission metrics such as Global Warming Potential (GWP) and Global Temperature change Potential (GTP) can be used to quantify and communicate the relative and absolute contributions to climate change of emissions of different substances, and of emissions from regions/countries or sources/sectors [original emphasis]. The metric that has been used in policies is the GWP, which integrates the RF [radiative forcing] of a substance over a chosen time horizon, relative to that of CO$_2$. The GTP is the ratio of change in global mean surface temperature at a chosen point in time from the substance of interest relative to that from CO$_2$. There are significant uncertainties related to both GWP and GTP, and the relative uncertainties are larger for GTP. There are also limitations and inconsistencies related to their treatment of indirect effects and feedbacks. The values are very dependent on metric type and time horizon.

**The choice of metric and time horizon depends on the particular application and which aspects of climate change are considered relevant**

\(^{547}\) Pro Oxygen, *supra* note 11.


\(^{549}\) Metz *et al.*, *supra* note 108, p. 10.


\(^{551}\) *Id.*, p. 663.
in a given context [emphasis added.] Metrics do not define policies or goals but facilitate evaluation and implementation of multi-component policies to meet particular goals. All choices of metric contain implicit value-related judgements such as type of effect considered and weighting of effects over time.

Given the dangers and the potential for surprises, as described at great length in section A.7, page 109, it should be crystal clear that use of the 100-year time horizon cannot be reconciled with the precautionary principle, principle 15 of the Rio Declaration—see section A.12, page 146.\footnote{supra note 80.}

The following is a quote from technical support section of the 2009 Endangerment Finding of the Environmental Protection Agency. In spite of the implied three-significant-digit accuracy of the greenhouse gas emissions, the percentages quoted change radically when a different time horizon is used in the following statistics cited by the Environmental Protection Agency:\footnote{supra note 44, ES-1.}

In 2007, U.S. GHG [greenhouse gas] emissions were 7,150 teragrams\footnote{The original note 1 reads: “One teragram (Tg) = 1 million metric tons. 1 metric ton = 1,000 kilograms = 1,102 short tons = 2,205 pounds.”} of CO$_2$-equivalent (TgCO$_2$eq).\footnote{As the original footnote 2 explains: Long-lived GHGs are compared and summed together on a CO$_2$-equivalent basis by multiplying each gas by its global warming potential(GWP), as estimated by IPCC. In accordance with United Nations Framework Convention on Climate Change (UNFCCC) reporting procedures, the U.S. quantifies GHG emissions using the 100-year timeframe values for GWPs established in the IPCC Second Assessment Report.} (TgCO$_2$eq). The dominant gas emitted is CO$_2$, mostly from fossil fuel combustion. Methane is the second largest component of U.S. emissions, followed by N$_2$O and the fluorinated gases (HFCs, PFCs, and SF$_6$). Electricity generation is the largest emitting sector (34% of total U.S. GHG emissions), followed by transportation (28%) and industry (19%).


Emitted during the production and transport of oil and natural gas as well as coal. Methane emissions also result from livestock and agricultural practices and from the anaerobic decay of organic waste in municipal solid waste landfills.

The report lists as the main global warming characteristics of CH$_4$ its average life time in the atmosphere, \textit{viz.} 12.4 years, and its 100-year GWP$_{100}$, namely (28–36), without any attempt to provide a scientifically sound justification for its use.\footnote{Id., p. 6.}

We conclude this section by referring to the aforementioned 2014 letter of 21 scientists to the Obama administration, a letter that addressed this same matter—see page 130.

In view of the timescale of the observed warming and its effect in the Arctic, as discussed in sections A.6.21.1, page 90, and A.6.21.2, page 91, only an energy policy should
be based on the carbon-equivalent expenditures defined in terms of the instantaneous global warming potential of methane. Accounting of the atmospheric chemistry and dynamics of non-CO$_2$ forcings by means of use of the GWP$_0$ and the principles specified in the Technical Appendix,\textsuperscript{558} B, page 150. Alternative, equivalent metrics can be found, but the must be consistent with the precautionary principle discussed in section A.12, page 146 and in the relief requested in this Petition.

A.11 Outpacing projections

The evaluation of climate models in chapter 9 of the 2013 Fifth Assessment Report concludes that the predictive capacity of the models has increased since it previous 2007 assessment.\textsuperscript{559} In this section we focus on some well-documented shortcomings that seem to come with both the “culture of science” of modelers, \textit{i.e.}, and the models themselves. Indeed, the aforementioned assessment contains the following comment relevant to the examples discussed:\textsuperscript{560}

The rate of melt water release from the Greenland and Antarctic ice sheets in response to climate change remains a major source of uncertainty in projections of sea level rise . . . .

A.11.1 Scientific bias

In 2012 the Scientific American ran a column entitled \textit{Climate Science Predictions Prove Too Conservative}.\textsuperscript{561} Its subtitle was:

Checking 20 years worth of projections shows that the Intergovernmental Panel on Climate Change has consistently underestimated the pace and impacts of global warming.

Here is another quote from the same column:

Oreskes, Oppenheimer and their co-authors argue the conservative bias pervades all of climate science. But the underestimation by the IPCC is particularly worrisome, scientists say, because the organization is charged specifically with advising policy makers on the most relevant, accurate climate science.

Indeed, Brysse \textit{et al.} wrote a paper entitled \textit{Climate change prediction: Erring on the side of least drama?}\textsuperscript{562} As the authors write, the issue is “that scientists are biased not toward alarmism but rather the reverse: toward cautious estimates, where we define caution as erring on the side of less rather than more alarming predictions.” In addition to the “culture of science,” which indeed produces this tendency, it is important to keep in mind that there is a vital distinction between pure science and science done to underpin policy making: in the former, the burden of the proof is on the scientist. Public policy, the other

\textsuperscript{558}Nightingale, supra note 33.


\textsuperscript{560}Id., p. 753.


\textsuperscript{562}Brysse \textit{et al.}, supra note 71.
hand, should be guided by the precautionary principle, i.e., the necessity of avoiding possibly low-probability, worst-case scenarios—see section A.12, page 146.

The following are some of the main conclusion of Brysse et al.:

- Climate scientists are not alarmists but have underestimated recent climate changes.
- We identify a directional bias toward erring on the side of least drama (ESLD).
- ESLD is an internal pressure arising from norms of objectivity, restraint, etc.
- ESLD may cause scientists to underpredict or downplay future climate changes.

### A.11.2 Model shortcomings

Not only is accurate prediction of water loss from ice sheets difficult, but the same applies to melting of sea ice. As Hansen et al. put it:

> Arctic sea ice end-of-summer minimum area, although variable from year to year, has plummeted by more than a third in the past few decades, at a faster rate than in most models, with the sea ice thickness declining a factor of four faster than simulated in IPCC climate models.

Indeed, as Brown and Caldeira note “rapid nonlinear melting of the Greenland and Antarctic ice sheets has some plausibility,” but is not represented in any of the models they studied in an update of projections contained in Intergovernmental Panel on Climate Change (IPCC)’s assessments. The paper projects warming for the end of the 21st century for the steepest radiative forcing scenario about 15% above these IPCC projections.

The following quote is from an other peer-reviewed paper addressing the same issue of outpaced projections:

> The observed rapid loss of thick multiyear sea ice over the last 7 years and the September 2012 Arctic sea ice extent reduction of 49% relative to the 1979–2000 climatology are inconsistent with projections of a nearly sea ice-free summer Arctic from model estimates of 2070 and beyond made just a few years ago.

That Arctic amplification, i.e., the fact that the Arctic is warming up more rapidly than the rest of the globe, and that the loss of sea ice is progressing faster than predicted by climate models has been known for quite some time. Indeed, Arctic sea ice thickness has...
contracted four times faster than predicted by Intergovernmental Panel on Climate Change (IPCC) climate models.\footnote{P. Rampal \textit{et al.}, “IPCC climate models do not capture Arctic sea ice drift acceleration: Consequences in terms of projected sea ice thinning and decline.” In: \textit{J. Geophys. Res., 116, C00D07} (2011), pp. 1–17. DOI: 10.1029/2011JC007110.}

The profound changes of the Arctic system influence mid-latitude weather and are related to extreme cold events over the U.S. during the early winter of 2014.\footnote{T. Vihma, “Effects of Arctic Sea Ice Decline on Weather and Climate: A Review.” In: \textit{Surveys in Geophysics} 35 (2014), pp. 1175–1214. DOI: 10.1007/s10712-014-9284-0. URL: \url{https://link.springer.com/content/pdf/10.1007%2Fs10712-014-9284-0.pdf}.} For more on this we refer to page \footnote{J. Cohen \textit{et al.}, “Recent Arctic amplification and extreme mid-latitude weather.” In: \textit{Nature Geoscience} 7.9 (2014), pp. 627–637. DOI: 10.1038/NGEO2234. URL: \url{https://www.nature.com/articles/NGEO2234}.} 62. As a recent review of this connection mentions in its abstract: “The exact nature of these non-linear interactions is not well quantified but they provide potential high-impact risks for society.”\footnote{D. Coumou \textit{et al.}, “The influence of Arctic amplification on mid-latitude summer circulation.” In: \textit{Nature Communications} 9.1 (Jan. 2018). DOI: 10.1038/s41467-018-05256-8.}

Not only do climate models underestimate the loss of sea ice, observations show that the same applies to the Greenland Ice Sheet.\footnote{Schaefer \textit{et al.}, supra note 448.}

Our observations are incompatible with most existing model simulations that present a continuously existing Pleistocene GIS. Future simulations of the GIS should take into account that Greenland was nearly ice-free for extended periods under Pleistocene climate forcing.

In their 2007 paper \textit{Recent Climate Observations Compared to Projections} the authors write:\footnote{S. Rahmstorf \textit{et al.}, “Recent Climate Observations Compared to Projections.” In: \textit{Science} 316.5825 (2007), p. 709. URL: \url{http://science.sciencemag.org/content/sci/316/5825/709.full.pdf} (visited on Nov. 28, 2017).}

Overall, these observational data underscore the concerns about global climate change. Previous projections, as summarized by Intergovernmental Panel on Climate Change (IPCC), have not exaggerated but may in some respects even have underestimated the change, in particular for sea level.

Five years later in a follow up with the same lead author we find:\footnote{S. Rahmstorf, G. Foster, and A. Cazenave, “Comparing climate projections to observations up to 2011.” In: \textit{Environmental Research Letters} 7.4 (2012), p. 044035. URL: \url{http://stacks.iop.org/1748-9326/7/i=4/a=044035}.}

We analyze global temperature and sea-level data for the past few decades and compare them to projections published in the third and fourth assessment reports of the Intergovernmental Panel on Climate Change (IPCC). The results show that global temperature continues to increase in good agreement with the best estimates of the IPCC, especially if we account for the effects of short-term variability due to the El Niño/Southern Oscillation, volcanic activity and solar variability. The rate of sea-level rise of the past few decades, on the other hand, is greater than projected by the IPCC models. This suggests that IPCC sea-level projections for the future may also be biased low.

Also the \textit{Third National Climate Assessment} of 2014 mentions the matter of outpaced projections, as illustrated in Fig. 24.\footnote{Melillo, Richmond, and Yohe, supra note 77, p. 48.}

The assessment states:\footnote{\textit{Id.}, p. 2.}
It is notable that as data records have grown longer and climate models have become more comprehensive, earlier predictions have largely been confirmed. The only real surprises have been that some changes, such as sea level rise and Arctic sea ice decline, have outpaced earlier projections.

Figure 24: Observed rate of decline exceeds even latest IPCC/CIMP5 scenario.

![Projected Arctic Sea Ice Decline](image)

Figure 2.29. Model simulations of Arctic sea ice extent for September (1900-2100) based on observed concentrations of heat-trapping gases and particles (through 2005) and four scenarios. Colored lines for RCP scenarios are model averages (CMIP5) and lighter shades of the line colors denote ranges among models for each scenario. Dotted gray line and gray shading denotes average and range of the historical simulations through 2005. The thick black line shows observed data for 1953-2012. These newer model (CMIP5) simulations project more rapid sea ice loss compared to the previous generation of models (CMIP3) under similar forcing scenarios, although the simulated September ice losses under all scenarios still lag the observed loss of the past decade. Extrapolation of the present observed trend suggests an essentially ice-free Arctic in summer before mid-century.\(^{139}\) The Arctic is considered essentially ice-free when the areal extent of ice is less than one million square kilometers. (Figure source: adapted from Stroeve et al. 2012\(^{136}\)).

Not only the scientific but also the national security community is aware of the fact that developments are outpacing projections as this quote illustrates:\(^{579}\)

If, continuing the trend of recent years, scenarios and projections of coastal impacts continue to grow more worrisome as they are refined, the defense community should assume that some of what we now believe are worst-case scenarios may actually become the median or even best-case scenarios.

As a recent review article puts it: 580

Comparison of palaeo observations with climate model results suggests that, due to the lack of certain feedback processes, model-based climate projections may underestimate long-term warming in response to future radiative forcing by as much as a factor of two, and thus may also underestimate centennial-to-millennial-scale sea-level rise.

For some of these under-predictions there is a simpler explanation. When all one has is a relatively short, noisy time-series, most scientists tend to simply draw a straight line through the data. That in many cases seems to be the only option. Given the doubling time of three to four decades of the exponential growth in the greenhouse gas built up since the Industrial Revolution, most time series obtained by direct observation are short indeed, certainly too short to make an independent, reliable estimate of the doubling time. However, one can—and when respecting the precautionary principle (see section A.12, page 146) in fact one should—use the doubling time implied by the growth in atmospheric CO₂ as the basis for curve fitting. 581 This indeed is how we obtained the red line drawn though the original noisy blue curve shown in Fig. 25 and the same applies to the temperature anomaly shown in Fig. 9, on page 54.

Figure 25: Accelerating monthly decline of the Greenland ice sheet (solid blue), consistent with the exponential increase (solid red) in atmospheric CO₂ and the temperature anomaly shown in Figs. 8 and 9 on page 54.

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580 Fischer et al., supra note 234.
581 As mentioned before, in note 299, as to the fitted parameters, this is a linear regression, although the fitted curve is nonlinear.
There are many examples we could cite, so many that it is impossible to be exhaustive. We do list some typical examples; also see the discussion under the heading Nonlinear Trends on page 72. For instance, although it is clear that the trend in Fig. 26 is nonlinear, as the upward curvature of the blue line shows, the authors fit the data with straight lines to produce the linear trends they cite in Table 1 with 95% confidence levels. Obviously, this kind of curve-fitting results in systematically underestimated projections.

Figure 26: Ocean heat content and atmospheric CO₂ concentration measurements since 1958, shown as 12-month running means. The black line represents ocean heating for the upper 2,000 meters of ocean, and light red shading represents the 95% confidence interval. CO₂ concentration observed at Mauna Loa Observatory is displayed by light blue. Mean values for 2015–2016 are highlighted with a red star. The ocean heat content is relative to a 1960–2015 baseline.

The very same underprediction presumably by linear extrapolation is encountered in the conclusion of Restoring the quality of our environment, the 1965 report to President Lyndon B. Johnson. The authors note that “[t]he EEI has implications for the future and should be fundamental in guiding future energy policy and decisions; it is the heartbeat of the planet. Changes in OHC, the dominant measure of EEI, should be a fundamental metric along with SLR.

As we continue to scrutinize the fidelity of specific climate models, it is critical to validate their energetic imbalances as well as their depiction of GMST.” The following may help the non-expert reader decode this statement:

**EEI:** Earth’s energy imbalance;
**OHC:** ocean heat content;
**SLR:** sea level rise;
**GMST:** global mean surface temperature.


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OHC: ocean heat content;
SLR: sea level rise;
GMST: global mean surface temperature.

*supra* note 58, p. 127.
Fig. 27 shows another example of linear fits used to describe an obviously accelerating trend. Its source is Environmental Protection Agency’s Endangerment Finding.  

Figure 27: Linear fits to describe a clearly accelerating trend. Quoted by Environmental Protection Agency in its technical support for its Endangerment Finding

A.11.3 Other possible sources bias

Much of the material presented in this chapter is based on the *Fourth National Climate Assessment* of 2017 and is organized around its chapters and findings. Additional facts are interpolated in separate sections. The reliance of this Petition on this Fourth Assessment may have introduced a bias in the presentation, as shown by the following:

- In the *Third National Climate Assessment* of 2014 the term “Indigenous Peoples” occurs 110 times; in the Fourth Assessment the terms does not occur.

- “Vulnerable populations” occurs 17 times in the Third Assessment, but not in the Fourth.

- “Justice,” modified by “climate,” “social” or “environmental” occurs 19 times in the Third and not at all in the Fourth.

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28 EPA-TechSup-12-7-2009

586 The scientific bias will be discussed at length in section A.11, page 138. Possibly, “vulnerable” etc. be in Volume II of the 2017 *Fourth National Climate Assessment.*

587 Melillo, Richmond, and Yohe, supra note 77.

588 An exception is someone by the name of C.O. Justice.
A SCIENTIFIC BACKGROUND—DETAILS

Another source of bias is due to the political appointments to the agencies involved in producing the *Fourth National Climate Assessment*. The Trump administration has made denial of science as a whole and of climate science in particular an article of faith.

As to “vulnerable populations” the following is particularly noteworthy:

Policy analysts at the Centers for Disease Control and Prevention in Atlanta were told of the list of forbidden words at a meeting Thursday with senior CDC officials who oversee the budget, according to an analyst who took part in the 90-minute briefing. The forbidden words are “vulnerable,” “entitlement,” “diversity,” “transgender,” “fetus,” “evidence-based” and “science-based.”

As mentioned on page 40 and in note 370, the Trump administration is also “making it harder to find government information about climate change on the web.”

Although matters have become dramatically worse, political bias was also present during the Obama administration. A particularly important case involves the Environmental Protection Agency:

New documents have emerged that show the EPA downplayed the risks of fracking in a landmark report on the process used to extract oil and gas from shale. The last minute changes made by the EPA are documented in a story by the public radio show Marketplace and APM Reports.

The topic of corporate influence and ideological polarization surrounding climate change have been clearly visible over the last decades. A systematic study concluded:

The main empirical and theoretical contribution of this analysis is that corporate funding influences the actual language and thematic content of polarizing discourse. These effects were visible over time, as the prevalence of certain thematic content shifted within the 20-year span of textual data. A secondary finding of this analysis is that organizations that received corporate funding were more likely to have written and disseminated contrarian texts. Taken together, these findings are especially important because they contribute comprehensive empirical evidence to confirm what has widely been thought to be the case about climate change knowledge and politics, but has heretofore not been demonstrated scientifically with robust data.

Note that although ExxonMobil and the Koch Family Foundations are mentioned in this study, it predates the latest, dramatic increase of corporate influence of these entities in particular on U.S. government.

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590 Rinberg and Bergman, supra note 168.


593 Id., page 2 of 6.
A.12 The essential importance of the Precautionary Principle

The pedestrian formulation of the Precautionary Principle is: better safe than sorry. Here are two other formulations:594

1. When an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.595

2. When the health of humans and the environment is at stake it may not be necessary to wait for scientific certainty to take protective action.

The precautionary principle also puts the burden of the proof of safety of activities and developments on their proponents:596

**Alternatives Assessment:** An obligation exists to examine a full range of alternatives and select the alternative with the least potential impact on human health and the environment, including the alternative of doing nothing.

Pivotal in the context of this Petition is the formulation contained in the Principle 15 of the Rio Declaration of 1992:597,598

In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

The following is a list of international treaties to which the U.S. is a party and in which the precautionary approach has been incorporated:599

1. 1992 United Nations Framework Convention on Climate Change:600

   The Parties should take precautionary measures to anticipate, prevent or minimize the cause of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, ....

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595 This is the formulation as it appears in the 1998 Wingspread Consensus Statement *(supra* note 51).


597 *supra* note 80.


2. 1995 Fish Stocks Agreement Equally relevant to the State of Rhode Island is the 1995 Fish Stocks Agreement. Part II, Article 5(c), explicitly states,$^{601}$ apply the precautionary approach in accordance with article 6;

More in detail:

Article 6
Application of the precautionary approach

(a) States shall apply the precautionary approach widely to conservation, management and exploitation of straddling fish stocks and highly migratory fish stocks in order to protect the living marine resources and preserve the marine environment.

(b) States shall be more cautious when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures.

(c) In implementing the precautionary approach, States shall:

i. improve decision-making for fishery resource conservation and management by obtaining and sharing the best scientific information available and implementing improved techniques for dealing with risk and uncertainty;

ii. ....

3. 1997 Protocol to the International Convention for the Prevention of Pollution From Ships:$^{602}$

- RECALLING Principle 15 of the Rio Declaration on Environment and Development which calls for the application of a precautionary approach,

4. 2000 Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean$^{603}$

Mindful that effective conservation and management measures require the application of the precautionary approach and the best scientific information available,

5. 2001 International Convention on the Control of Harmful Anti-Fouling Systems.$^{604}$


The U.S. is bound to the precautionary principle and that international treaties according to the Supremacy Clause of the U.S. Constitution are the supreme law of the land. Despite this most in the U.S. seem to be only very familiar with this concept in medical practice (first, do no harm). We do not apply this concept widely in the U.S. when it comes to drug safety, food safety, and the environment. Rather, concern about economic considerations often takes precedence when there are remaining scientific uncertainties.

Particularly relevant to the acidification and eutrophication observed in Narragansett Bay—as discussed on page 35 of section A.2.2—is the 1999 Protocol to the 1979 Convention on Long-range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-level Ozone, signed on December 1, 1999, and accepted by the U.S. on November 22, 2004, explicitly relies on the Rio Declaration in its preamble:

Resolved to take measures to anticipate, prevent or minimize emissions of these substances, taking into account the application of the precautionary approach as set forth in Principle 15 of the Rio Declaration on Environment and Development, ...
resources and ecosystems, damage amenities or interfere with other legitimate uses even when there is no conclusive evidence of a causal relationship between the inputs and the effects. All state entities and contracting parties shall take all necessary steps to ensure the effective implementation of the Precautionary Principle to environmental protection and to this end they shall:

(i) encourage prevention of pollution at source, by the application of clean production methods, including raw materials selection, product substitution and clean product technologies and processes and waste minimalization throughout society;

(ii) evaluate the environmental and economic consequences of alternative methods, including long term consequences;

(iii) encourage and use as fully as possible scientific and socioeconomic research in order to achieve an improved understanding on which to base long-term policy options.

In Europe, the concept is widely applied, and it has been adopted by a number of key U.S. organizations and localities—including, for example, the American Public Health Organization since 2000 with respect to the health of children. Moreover, there are a number of articles, and indeed at least one book, that provide examples of how applying this principle can lead to much better results, and how failure to do so has led to long delays in addressing health problems.

As pointed out throughout this chapter, we do know a great deal about climate change, and have developed and tested multiple models that allow us to predict trends with some certainty. But as noted in the last section in particular, there remain a number of uncertainties and surprises that could greatly accelerate the speed with which changes will occur. These changes, for example a quicker deterioration of the permafrost in the Arctic, or the sudden development of new viruses as a result of changing conditions, could be disastrous for Petitioners health.

This is why it is essential that in crafting solutions, we follow the lead of others throughout the world in taking a precautionary approach in our actions to address a problem on which error could well lead to extinction. The Rhode Island Administration has a history of ignoring this principle, and being over-cautious, if not negligent, in its actions to address climate change, notwithstanding their information on the scope and urgency of the threat to Petitioners.

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613 See the references in Id.
Proposed policymaker-friendly metric of radiative effects of greenhouse gases

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Abstract.
This paper proposes a simple metric for the dynamic evaluation of the cumulative, combined impact on global warming of greenhouse gases. As an illustration, the metric is applied to methane (natural gas) when used for energy production. The proposed metric accounts for the effect on a decadal timescale of energy policies based on natural gas as a purported bridge fuel. Results of a thought experiment evaluated by the proposed metric explicitly show problematic policy aspects of the commonly employed global warming potential of methane with a 100-year time horizon which:

1: lacks a solid scientific basis and is incompatible with crucial timescales;
2: does not allow for continuous-time dynamic tracking of greenhouse gas emissions; and
3: is incompatible with the Precautionary Principle.

1 Introduction

Hansen et al. (2008) argue that atmospheric CO$_2$ concentration exceeding 350 ppm poses a serious threat to human existence and life on earth in general. As the authors put it in their abstract:

If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO$_2$ will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that. The largest uncertainty in the target arises from possible changes of non-CO$_2$ climate forcings.

The paper warned that continued growth of greenhouse gas emissions for just another decade—after 2008—would make it practically impossible to avoid catastrophic effects on the climate system. A decade later, atmospheric CO$_2$ is fluctuating around 410 ppm (Pro Oxygen, 2018) and it still appears to be increasing at a rate roughly in the range of 2–2.5 percent per year.

In the aforementioned quote, the authors qualify the critical number, 350 ppm, mentioning that it is likely too high, as it fails to account fully for the dangers of non-CO$_2$ forcings. Of these, atmospheric methane is dominant. What is more, methane forcing today is far more impactful than it was in 2008. For instance, Turner et al. (2016) concluded on the basis of satellite
and surface data that there had been a large increase in the methane emissions of the United States over the decade prior to their study. Worden et al. (2017) subsequently traced this increase back to fossil fuel sources.

At the same time, as numerous publications over the last decade have made clear, the climate system is changing at a rate outpacing projections, those of the Intergovernmental Panel on Climate Change (IPCC) in particular. For instance, Rahmstorf et al. (2007) mention that projections may have underestimated changes in sea level rise. Hansen et al. (2013) mention that end of summer Arctic sea ice has been declining a factor of four faster than in IPCC models. Also the Third National Climate Assessment (Melillo et al., 2014) states that the “only real surprises have been that some changes, such as sea level rise and Arctic sea ice decline, have outpaced earlier projections.” Brown and Caldeira (2017) discuss rapid nonlinear melting of the Greenland and Antarctic ice sheets not represented in IPCC model assessments.

There are numerous other such under-predicted developments such as, for example, the Arctic amplification documented in recent Arctic Report Cards issued by the National Oceanic Atmospheric Administration (a, b). Underestimates should not come as a surprise. Indeed, Brysse et al. (2013) et al. discuss a series of examples of scientists “erring on the side of least drama.”

Developments of the cryosphere clearly have a large decadal component and indeed, as Steffen et al. (2018) and also Rintoul et al. (2018) have argued, decisions made during the next one or two decades may lead to irreversible changes of the climate system. Nonetheless, and in spite of critical observations of IPCC going back to its Second Assessment Report (Houghton et al., 1995), the global warming potential (GWP) with a 100-year time horizon has become the metric employed—pursuant to the United Nations Framework Convention on Climate Change (UNFCCC)—to assess public policy with respect to multi-gas (usually called CO$_2$ equivalent) emissions.

With the considerations in mind it should be noted that IPCC’s Fifth Assessment Report (AR5) explicitly states that there is no scientific argument for using the 100-year GWP horizon—see, e.g., page 711 of Stocker et al. (2013). In fact, as AR5 puts it: “All choices of metric contain implicit value-related judgements such as type of effect considered and weighting of effects over time.” Note against this background that Ocko et al. (2017) have pressed for more transparency in climate policy issues with respect to the often hidden implied temporal trade-offs.

The climate system of the earth is a complex system far from thermodynamic equilibrium with many inseparable time- and lengthscales. In such a system, uncontrolled, scientifically hard to justify approximations will always characterize any attempt to isolate simple metrics for use by policy makers to gauge—as was IPCC’s design purpose—the relative radiative effects of divers greenhouse gasses.

More specifically, as argued above, the disruption of the climate system of the earth and the human role in it clearly have important decadal timescale features. Given this, use of the 100-year horizon as the basis of major energy policy decisions has no basis in science. Whatever value judgments may have led to general acceptance of this 100-year metric, it appears to be irreconcilable with the Precautionary Principle, number 15 of the Rio Declaration of the United Nations General Assembly; United Nations Change Change. For further discussion of this see Section 2.

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1 The following is a representative list of comments about the global warming potential to be found in various IPCC assessments: Houghton et al. (1995) pages 21 and 73; and Stocker et al. (2013) pages 58, 663, 710, and 711.
In addition to these general considerations and because of the shift in the United States over the last decade to natural gas,\textsuperscript{2} which is used increasingly for the generation of electricity, it is imperative to provide policymakers with tools that do not downplay the effects of non-CO\textsubscript{2} emissions with very strong near-term effects on the climate.

The simple dynamical metric proposed here produces order of magnitude estimates based on the instantaneous global warming potential rather than the one based on the 100-year horizon. The results show that simple, user-friendly alternatives exist for the 100-year time horizon global warming potential. Edwards and Trancik (2014) presented a similar approach, one that also focuses on a dynamical approach rather than the static one implicit in the use of any non-instantaneous global warming potential.

The layout of the paper is as follows: Section 2 reviews some of the well-known basic properties of methane and introduces the proposed simple dynamical metric. Section 3 presents results of some simple energy policy thought experiments. Finally, Section 4 summarizes the conclusions.

2 Methane basics

The global warming potential, as mentioned in Section 1, is a simple tool designed to estimate the relative effect of greenhouse gasses on global warming. It was designed and accepted to assist in policy making. This quantity is a dimensionless multiplier that converts the effect of the emission of a unit mass pulse of a greenhouse gas under consideration to a mass of CO\textsubscript{2} that would have the same global warming effect, the CO\textsubscript{2} equivalent (CO\textsubscript{2e}) mass. A pulse of CO\textsubscript{2} injected into the atmosphere is taken up by the ocean, biosphere and soil and decays by half in about 25 years but 20\% is still in the atmosphere after 500 years; see Fig. 4A in Hansen et al. (2013). Atmospheric CH\textsubscript{4}, on the other hand, has a half-life of less than a decade.

More explicitly, the global warming potential, as defined in Section 8.7.1.2 of Stocker et al. (2013), is a fraction: the time-integral of the radiative forcing due to a pulse emission of a given greenhouse gas divided by same quantity for a pulse of an equal mass of CO\textsubscript{2}. Due to the atmospheric dynamics of both CO\textsubscript{2} and CH\textsubscript{4} the resulting global warming potential depends on the time interval used in the integrals, aka the time horizon. The global warming potential is denoted by \(G_t\) with \(t\) the time horizon in units of years.

The choice of the time horizon \(t\) is a major source of arbitrariness. In addition to the value judgment mentioned in Section 1 and acknowledged by the Intergovernmental Panel on Climate Change (IPCC), there is the issue of the timescales relevant to the physical process and policy decisions under consideration.

For a project small on a global scale, averaging emissions over the expected life time of that project might make physical sense, but for matters of global scale, such as the energy policy major global greenhouse gas emitting nations, the horizon should be set by the timescale of the global climate change phenomena and the danger they pose to life on earth. Therefore, as mentioned in Section 1, there notably are the following considerations, among others:

\textsuperscript{2}Exploration and production subsidies from the federal government have increased dramatically, during the Obama administration; see, e.g, Oilchange International. This trend is expected to accelerate during the Trump administration.
1. The arguments made by Hansen (2005) and the well-known difficulty of predicting instabilities (aka state shifts or tipping points) such as the sudden and, on a human multi-generational timescale irreversible, disintegration of ice sheets; i.e., as Drijfhout et al. (2015) put it, the fact that tipping points “notoriously difficult to foresee;”

2. Recent developments on a decadal timescale in the Arctic (National Oceanic Atmospheric Administration, a, b);

3. The fact that decisions made in the next one or two decades may determine the fate of the future of Antarctica and the Southern Ocean, as argued by Rintoul et al. (2018) argue, or set the climate system on a for all practical purposes irreversible trajectory to what Steffen et al. (2018) refer to as “Hothouse Earth;”


Based on these matters, and the simple, mathematical fact that non-instantaneous global warming potentials cannot be used straightforwardly in a dynamical approach, the metric proposed in this paper uses the instantaneous global warming potential $G_0$, the instantaneous radiative forcing relative to that of CO$_2$.

The effect of the choice of the time horizon manifests itself explicitly in the critical fraction $f_c$ of fugitive CH$_4$ above which the global warming impact of the unburned, fugitive methane cancels out its higher energy density per unit emitted CO$_2$. To find $f_c$, suppose one generates energy from one mole of CH$_4$ a fraction $f$ of which escapes unburned. The part that is burned adds $(1-f)$ moles of CO$_2$ to the atmosphere. Given $G_t$, the global warming potential of CH$_4$, the fraction $f$ of fugitive CH$_4$ adds $(4/11)fG_t \equiv G'_t$ to the atmospheric CO$_2$ equivalent. The total increase is $1-f+fG'_t$. Note that the molecular mass ratio $4/11$ of CH$_4$ and CO$_2$ appears because of the conventional definition of the global warming potential $G_t$, which compares the effects of a unit mass of CH$_4$ of to the effect of the same mass of CO$_2$, rather than the same number of moles; see (Stocker et al., 2013, p. 710).

Different fuels emit different amounts of CO$_2$ per unit energy produced upon combustion. Suppose that per unit CO$_2$ produced, CH$_4$ generates a factor $\varepsilon$ more energy than some other fuel, say coal or oil. For coal the calculations in this paper use typical values: $\varepsilon = 2$ and for oil $\varepsilon = 4/3$ (U.S. Energy Information Administration (EIA), 2018). Taking into account the fugitive gas loss of CH$_4$, to produce the same amount of electric energy as from CH$_4$, one has to burn a relative amount of $(1-f)\varepsilon$ coal or oil.

The critical fraction $f_c$ for which both processes have the same impact on the climate follows from the equation

$$1 - f_c + f_cG'_t = (1 - f_c)\varepsilon,$$

so that

$$f_c = \frac{\varepsilon - 1}{\varepsilon - 1 + G'_t}.$$
Table 1. Critical fractions $f_c$ for coal and oil for global warming potentials $G_t$ with various time horizons $t$ in units of years.

<table>
<thead>
<tr>
<th></th>
<th>$G_0 = 120$</th>
<th>$G_{20} = 34$</th>
<th>$G_{100} = 86$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon = 2$ (coal)</td>
<td>2.2%</td>
<td>3.1%</td>
<td>7.5%</td>
</tr>
<tr>
<td>$\varepsilon = \frac{4}{7}$ (oil)</td>
<td>0.76%</td>
<td>1.1%</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

Before discussing the relevant kinetic equations, we recall that the solution of the decay equation with decay time $\tau$ for any $g(t)$ with source $s(t)$ subject to initial condition $g(0) = 0$,

$$\dot{g}(t) = -\frac{g(t)}{\tau} + s(t),$$  \hspace{1cm} (3)

where $\dot{g} = dg/dt$, is given by

$$g(t) = \int_0^t e^{-\frac{t-t'}{\tau}} s(t') dt',$$  \hspace{1cm} (4)

for $t \geq 0$.

For the kinetic equations it is convenient to use molar number densities: $c(t)$ for CO$_2$, $m(t)$ for CH$_4$, and $c_e(t)$ for the CO$_2$ equivalent of the mix. Generalization is straightforward, but to simplify the thought experiment presented in this paper and obtain the order-of-magnitude estimates of interest—the results of which are in Section 3—it suffices to account only for the greenhouse gases CO$_2$ and CH$_4$. The CO$_2$ equivalent is given by:

$$c_e(t) = c(t) + G'_0 m(t).$$  \hspace{1cm} (5)

Because of the mass convention used in the definition of the global warming potential, this equation once again contains $G'_0$ rather than $G_0$. A further assumption in this thought experiment is that all of the increase in atmospheric CO$_2$ comes from the hypothetical future use of methane only. As a consequence, there are the following sources for increased emissions: (i) the combustion of CH$_4$; and (ii) the oxidation of fugitive CH$_4$ as it decays in the atmosphere. This will correspond to two source terms in the kinetic equations.

That is, if $p(t)$ is the rate of increase in CO$_2$ produced by coal or oil, using methane to generate the same power, yields the following rate of increase of CO$_2$:

$$\dot{c}(t) = \frac{p(t)}{\varepsilon} + m(t)/\tau,$$  \hspace{1cm} (6)

where the last term arises from the CO$_2$ production rate due to the oxidation of atmospheric CH$_4$; here $\tau = 12.4$ year, the atmospheric decay time of CH$_4$ ((Stocker et al., 2013, Table 8.7)). The rate of increase of CH$_4$ is:

$$\dot{m}(t) = -\frac{m(t)}{\tau} + \frac{f}{(1-f)\varepsilon} p(t),$$  \hspace{1cm} (7)

the last term accounts for the emission of fugitive CH$_4$. The desired solution of the differential equations corresponds to the hypothetical case in which for $t < 0$ power generated by combustion of coal and oil only. At $t = 0$ the a complete switch takes
place to CH₄. The corresponding solution, subject to initial condition \(m(0) = 0\)—a simplification made for the purpose of this thought experiment—is

\[
m(t) = \int_{0}^{t} e^{-(t-t')/\tau} \frac{f}{(1-f)\varepsilon} p(t_1) \, dt_1.
\] (8)

Substitute Eq. (8) into Eq. (6) and integrate, assuming \(c(-\infty) = 0\)

\[
c(t) = \int_{-\infty}^{0} p(t_1) \, dt_1 + \int_{0}^{t} \left[ \frac{p(t_1)}{\varepsilon} + \frac{m(t_1)}{\tau} \right] \, dt_1.
\] (9)

An additional assumption made in the choice of this metric is that CO₂ is treated as an atmospheric gas with an infinite decay time. In other words, for CO₂ the first term on the right-hand side of Eq. (3) vanishes, so that CO₂ evolves by simply adding up for ever. The justification for this approximation is that, as shown by Matthews et al. (2009), the total allowable emissions, i.e., the budget for climate stabilization, is approximately independent of the time and place of those emissions. At the same time, the metric developed here is set up so that policy makers can track the expenditures to be charged to that budget as a result of their policies.

The final result for the atmospheric CO₂ equivalent concentration at time \(t > 0\) is obtained by substituting Eqs. (8) and (9) into Eq. (5). Subject to the specified initial conditions, the solution of the differential equations is:

\[
c_{\text{e}}(t) = \int_{-\infty}^{0} p(t) \, dt + \frac{1}{\varepsilon} \int_{0}^{t} p(t_1) \, dt_1 + \frac{f}{(1-f)\varepsilon} \left[ G_0^t \int_{0}^{t} e^{\frac{t-t_1}{\tau}} p(t_1) \, dt_1 + \frac{1}{\tau} \int_{0}^{t} \int_{0}^{t_1} e^{\frac{t_2-t}{\tau}} p(t_2) \, dt_2 \, dt_1 \right].
\] (10)

Note that the first two terms represent the cumulative emissions since the Industrial Revolution, approximated here as having occurred at \(t = -\infty\) and the additionally accumulated amount as of \(t = 0\), when the in this thought experiment hypothetical switch to CH₄ occurs. The third term represents the CO₂-equivalent of the accumulated fugitive CH₄. The fourth term accounts for the accumulated CO₂ by oxidation of fugitive CH₄, oxidized at various times starting at \(t = 0\).

In the case discussed in this paper, the function \(p\) is represented accurately by a simple exponential, as shown in the next Section 3, so that the integrals can be done exactly; in more complicated cases, numerical integration is straightforward. In practical applications of a dynamical scheme of this sort, it would suffice to use a finite-difference approximation based on yearly data and appropriately chosen initial conditions.

### 3 Results

Estimates of total carbon dioxide emissions from the beginning of the Industrial Revolution are available from the Carbon Dioxide Information Analysis Center (CDIAC) (2014). As shown in Fig. 1, the data can be represented surprisingly accurately by a simple exponential growth curve; the curve shown in Fig. 1 satisfies the equation

\[
C_{\text{global}}(t) = 9.00 e^{0.025(\frac{t}{\text{year}} - 2010)} \text{GtC/year.}
\] (11)
This equation is used to define business-as-usual. The expression was obtained by a least squares fit, followed by a slight adjustment of the normalization constant so that the integral from $-\infty$ to year 2011 reproduces

$$\int_{-\infty}^{2011 \text{ year}} C_{\text{global}}(t) \, dt = 365 \text{ GtC},$$

the CDIAC estimate of 2011 cumulative emissions.

Given that CO$_2$ emissions are the predominant driver of global warming, it is not surprising that temperature anomaly $T$, shown in Fig. 2, is consistent with the climate forcing resulting from these emissions. The temperature anomaly data of NASA/GISS (NASA, 2017) can be used for a linear regression, two-parameter least-squares fit using the same exponential function featured in Eq. (11). This yields the following expression

$$T(t) = -0.3^\circ C + 1.0^\circ C e^{0.025(t-2010)},$$

shown as the solid curve in Fig. 2.

Here are the results of one thought experiment: assume, first of all, that business-as-usual continues and that global energy consumption keeps growing exponentially, and, secondly, that power is generated by combustion of coal or oil before 2018 and of CH$_4$ after that, corresponding to time $t = 0$ in Section 2 and the vanishing upper limit in the first integral and lower limits of the integrals in Eq. (10).

This produces Fig. 3 in which the solid black curve on the left represents the actual, historical development, a trajectory continued on the right. The blue curve starting in 2018 corresponds to a hypothetical, complete switch to CH$_4$ in that year with 6% of the CH$_4$ escaping unburned, i.e., half of the estimate in Howarth (2015). The red curve corresponds to 12% fugitive CO$_2$. Also included is a black-dashed curve for the critical fraction of fugitive methane as specified in Tab. 1. Fig. 4 is the
Figure 2. Temperature anomaly, the change in the global surface temperature relative to 1951–1980 average temperature (NASA, 2017). Dots represent five-year moving averages; the solid curve is given by Eq. (13).

Figure 3. Four emission scenarios: (1) Business-as-usual using coal (black curve); after 2018: (2) CH$_4$ with 6% fugitive (blue); (3) CH$_4$ with 12% fugitive (red curve); (4) CH$_4$ with critical fugitive fraction, (dashed) 2.2%, as shown in Tab. 1.

same assuming that combustion of oil generates power before 2018. Because the efficiency increase is considerably less in this case, the deleterious effect of the fugitive CH$_4$ is more pronounced.

Of course real life is not quite as simple as this thought experiment. However that may be, the results strongly suggest that, although the red and blue CH$_4$ curves will ultimately cross the black coal or oil curves, this does not happen sufficiently rapidly, i.e. within one or two decades, to justify the purported role of CH$_4$ as a bridge fuel.
Business-as-usual is one pathway, another one is to stay within a finite carbon budget. Fig. 5 shows two pathways to phase out fossil fuels starting in 2018. These pathways are consistent with the carbon budget proposed by Hansen et al. (2013). The area under both curves starting at $t = -\infty$, that is the total CO$_2$ put into the atmosphere, is 525 GtC, a number chosen because it reproduce the rates of emission reduction contained in the Hansen et al. (2013) paper, i.e. 3.5% in 2003, 6% in 2013, and 15% in 2020.
In Fig. 6, the black curve shows cumulative emissions corresponding to a phase-out of fossil fuels following the exponentially decaying pathway, the blue curve in Fig. 5. The blue curve corresponds to a complete switch-over from coal to CH₄ in 2018.

**Figure 6.** Four emission scenarios: exponential phase out of fossil fuel assuming (1) coal (black curve); (2) after 2018: CH₄ with 6% fugitive (blue); (3) CH₄ with 12% fugitive (red); (4) CH₄ with critical fugitive fraction, 2.2% (dashed), as shown in Tab. 1.

with 6% fugitive CH₄; the red curve is the analog with 12% fugitive CH₄. Fig. 7 differs only in that the switch-over is from

**Figure 7.** Four emission scenarios: Exponential phase out of fossil fuel assuming (1) oil (black curve); after 2018: (2) CH₄ with 6% fugitive (blue); (3) CH₄ with 12% fugitive (red); (4) CH₄ with critical fugitive fraction, 0.76% (dashed), as shown in Tab. 1.
oil to CH$_4$. Once again, because the increase in efficiency (4/3) is less in this case, the relative importance of fugitive CH$_4$ is more pronounced. In both cases the dashed curves correspond to the respective fugitive fractions of coal and oil.

4 Conclusions

Overspending the carbon budget (mentioned in Section 2) while maintaining a for humans habitable climate is unlikely to be compatible with the time table imposed by the laws of nature. The required replacement of fossil fuels by renewables and energy conservation requires global collaboration and redistribution of wealth on an unprecedented scale. In this context it is worth noting that Hansen et al. (2017) have concluded, in view the industrialized world’s lack of action since Hansen et al. (2013), that the climate can only be stabilized by “negative emissions,” i.e., by extracting CO$_2$ from the atmosphere.

As illustrated in Figs. 3, 4, 6, and 7, application of the policymaker-friendly tool proposed in this paper—a tool based on the instantaneous global warming potential—clearly supports what has been clear for some time, namely that “By The Time Natural Gas Has A Net Climate Benefit You’ll Likely Be Dead And The Climate Ruined,” as Joe Romm summarized it in the title of one of his post (Romm, 2014).

In other words, the order-of-magnitude time estimates implied by the graphs presented in Section 3 underscore that there is no scientific justification for using the 100-year horizon in energy policy choices involving natural gas as a bridge fuel. Indeed, reporting based on CO$_2$ equivalents using the 100-year horizon, which is standard practice (World Resoures Institute & World Business Council For Sustainable Development, 2013), obscures short-term effects and is irreconcilable with both the observed timescale of developments of the climate system (National Oceanic Atmospheric Administration, a, b; Hansen et al., 2017) and with that of policy making, a point made by Steffen et al. (2018); Rintoul et al. (2018).

Employing the proposed policy tool, the numerical thought experiments presented in Section 3 demonstrate that using more a realistic, continuous-time dynamic approximation—one that is consistent with the timescale of climate change—is technically straightforward. At the same time, such a tool that respects the relevant timescales may be pivotal in public policy making that stands a chance of preserving a habitable climate for present and future generations.

There is general agreement that humanity has a finite carbon budget overspending of which is likely to cause irreparable harm to life on earth. The Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5) quoted as its estimate for this budget 2900 GtCO$_2$ (Intergovernmental Panel on Climate Change, 2014). Accounting for the molar mass ratio (12/44) of carbon to carbon-dioxide this corresponds to 800 GtC. This number rests on the ill-founded, by now mostly abandoned, assumption that a 2°C global mean temperature increase is a “guardrail” that protects the biosphere from the essentially irreversible harm of run-away climate change (Geden, 2015; Friedman, 2015; Knutti et al., 2016). Indeed, the climate science research over last decades implies that relying on this upper limit is irreconcilable with the precautionary approach of Principle 15 of the 1992 Rio Declaration, a treaty signed and ratified by many countries, including the United States (National Oceanic and Atmospheric Administration—Office of General Counsel).

Fig. 5 is consistent with 1°C as the “guardrail,” a choice based on paleoclimate and other arguments presented in detail by Hansen et al. in (Hansen et al., 2008, 2013; Hansen and Kharecha, 2013; Hansen et al., 2017). This simple policy tool presented
here can keep track of how much of the global greenhouse gas budget is spent in carbon-equivalent units, defined in a way that is consistent with the Precautionary Principle.

As Figs. 6 and 7 make clear, there is no scientific argument can be made for phasing out fossil fuels while at the same time engaging in replacing coal and oil power plants by natural gas-fired ones. The same, but to an even higher degree—as is clear from the critical fugitive fractions in Tab. 1—applies to the introduction of natural gas vehicles, a conclusion supported by a “pump-to-wheels” study by Clark et al. (2017) that does not take into consideration the full life-cycle, “wells-to-wheels” emissions associated with propulsion.

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In 2017, there were 16 weather and climate disaster events with losses exceeding $1 billion each across the United States. These events included one drought event, two flooding events, one freeze event, eight severe storm events, three tropical cyclone events, and one wildfire event [National Oceanic and Atmospheric Administration (NOAA), National Centers for Climate Information].

This diagram shows sea level position for the last five million years since the end of the Miocene and the beginning of the Pliocene. Sea level is established here using an “albedo proxy.” (Credit: Root Routledge, created from source information and graphs from James Hansen publications. Copyright Root Routledge, but available for non-commercial distribution.)

A list of tipping elements reproduced from the Fourth National Climate Assessment.

Water, food, and fossil fuel energy are inextricably linked.

Burgeoning cities put enormous pressure on urban infrastructure—pressure that is only exacerbated by the effects of climate change, such as flooding.

Density-equalizing cartogram: Comparison of undepleted cumulative CO$_2$ emissions by country for 1950–2000 versus the regional distribution of four climate-sensitive health consequences (malaria, malnutrition, diarrhea, and inland flood-related fatalities).

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Linear fits to describe a clearly accelerating trend. Quoted by Environmental Protection Agency in its technical support for its Endangerment Finding.

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