AN UPDATE ON THE CLIMATE CRISIS: FROM SCIENCE TO SOLUTIONS

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY HOUSE OF REPRESENTATIVES

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C O N T E N T S

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Appendix II: Additional Material for the Record

AN UPDATE ON THE CLIMATE CRISIS: FROM SCIENCE TO SOLUTIONS

WEDNESDAY, JANUARY 15, 2020

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Committee met, pursuant to notice, at 10:01 a.m., in room 2318 of the Rayburn House Office Building, Hon. Eddie Bernice Johnson [Chairwoman of the Committee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

An Update on the Climate Crisis: From Science to Solutions

Wednesday, January 15, 2020
10:00 a.m.
2318 Rayburn House Office Building

PURPOSE

The purpose of this hearing is to provide an update on of the state of climate science. The Committee will receive expert testimony on significant climate reports published in 2019 and will discuss report findings that include: climate change impacts to our lands, oceans, and the cryosphere, and associated risks to human society and ecosystems; the gap in anticipated global emissions and emissions levels needed to keep global temperatures below 1.5°C or 2°C of warming above preindustrial levels. Additionally, witnesses will discuss opportunities to address climate change impacts through adaptation and mitigation. This hearing will specifically touch on the findings of the following three reports: 1) IPCC Special Report: Climate Change and Land, August 2019; 2) IPCC Special Report: The Ocean and Cryosphere in a Changing Climate, October 2019; 3) United Nations Environment Programme: Emissions Gap Report 2019, November 2019.

WITNESSES

- **Dr. Pamela McElwee,** Associate Professor of Human Ecology, School of Environmental and Biological Sciences, Rutgers, The State University of New Jersey
- **Dr. Richard Murray,** Deputy Director & Vice President for Research, Woods Hole Oceanographic Institution
- **Dr. Heidi Steltzer** - Professor of Environment and Sustainability, Fort Lewis College, Colorado
- **Mr. Michael Shellenberger,** Founder and President, Environmental Progress
- **Ms. Taryn Fransen,** Senior Fellow, Global Climate Program, World Resources Institute

OVERARCHING QUESTIONS

- What does the most recent science tell us about how climate change impacts lands, oceans and the cryosphere, and how do these impacts affect people and ecosystems?
- What impacts are Americans already experiencing due to climate change, and what impacts are projected to occur?
- What solutions to address climate change and reduce greenhouse gas emissions are ready for implementation, and which require additional investment?
- What actions should the United States take to adapt to and mitigate impacts from climate change?

BACKGROUND

IPCC Special Report on Climate Change and Lands

The Intergovernmental Panel on Climate Change (IPCC) [1] Special Report on Climate Change and Lands (Lands Report)[2] examines the interplay between land use and anthropogenic climate change. This includes how land use affects the degree and impacts of climate change, how climate change in turn impacts the land, and how policy reform and behavior change can offer climate solutions.[3] The Lands Report represents a synthesis of over 7000 academic papers and was prepared by 107 scientists from 52 countries. This report represents a major milestone, as it is the first IPCC Report with more authors from developing nations, which will experience the worst impacts of climate change, than authors from developed nations.[4]

The Lands Report emphasizes that climate impacts on land are already severe, and that land use in turn is a significant driver of climate change. In some areas, land is degrading due to more frequent and intense heat waves and droughts; rainfall patterns are shifting in frequency and in intensity;[5] crop yields and livestock productivity are diminished;[6] and risks from agricultural pests and diseases are changing.[7] Human behaviors and land management policies are driving intensive exploitation which is also degrading land. For example, agricultural soil is degrading at rates 10 to 100 times faster than it is formed.[8]

The Lands Report also evaluates climate impacts on food security in terms of availability from yield and production, access in terms of prices and ability to get food, utilization in nutrition and cooking, and stability from disruptions.[9] Warming of 2°C threatens a food crisis, with disproportionate risks for tropical and sub-tropical regions. Climate change may impact the nutritional content of foods, and water scarcity will increasingly become a dire problem with every increment of warming. Climate change can drive migration and can impact the food system from production to supply chain.[10] Nearly one-third of food produced is currently wasted, presenting opportunities to improve food security.[11] Also, plant-based diets or sustainably-produced animal sources of food offer opportunities to reduce emissions and adapt to stressed conditions.[12]

Agriculture, deforestation, and other land management practices contribute significantly to the

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[1] The IPCC is a United Nations (UN) body responsible for scientific assessments of climate change, with an aim to inform policymakers on climate science, implications, and strategies. It was established by the UN Environment Programme and World Meteorological Organization in 1988. It has 195 member states. It produces periodic Assessment Reports (AR) every four to six years, as well as Special Reports, which undertake interdisciplinary issues that span more than one of its three Working Groups. Special Reports are typically shorter and more focused. At its 41st Session in 2015, the IPCC decided to produce a Methodology Report, AR6, and three Special Reports, on Global Warming of 1.5°C, Oceans and Cryosphere in a Changing Climate, and Climate Change and Land.
[2] IPCC, 2019: Special Report on Climate Change and Lands https://www.ipcc.ch/srccl/ (Lands Report)
[3] Summary for Policymakers, Lands Report
[4] https://www.ipcc.ch/2019/08/08/land-is-a-critical-resource_srccl/
[5] Ibid. at 2: Section A2
[6] Ibid. at 2: Section A5
[7] Ibid. at 2: Section A2
[8] Ibid. at 2: Section A1
[9] Ibid. at 2: Section A2
[10] Ibid. at 2: Section A5
[11] Ibid. at 2: Section A1
[12] Ibid. at 2: Section B6

carbon cycle and climate change overall, producing about 23% of anthropogenic emissions. The agricultural sector can play a critical role in climate solutions. Land is both a source and sink of greenhouse gas (GHG) emissions and absorbs 29% of GHGs humans emit annually into field soils and plant growth. However, this ability of land to soften the impacts of climate change is limited, as the ability of soils to perform this function diminishes as temperatures rise. [13]

Early progress toward a far-reaching transformation of agriculture, forestry, and land use, with actions well underway by 2040, is necessary to reach the goals of the Paris Agreement. Improving agricultural practices through better soil management, genetics, and agroforestry, is both possible and often a mutually beneficial solution for both reducing emissions and maintaining or boosting production levels.[14] Stopping deforestation should be a critical global policy priority and restoring forests can store atmospheric carbon. [15] However, the report says that some policies, such as afforestation and bioenergy with carbon capture and sequestration, must be implemented carefully; these policies can create competition with land for food crops, which can exacerbate food insecurity.[16] Timelines are short for preserving agricultural productivity, land quality, biodiversity, and food security. The agricultural sector faces the shortest window to implement successful adaptation and mitigation measures due to the diminishing capability of fields to store carbon and diminishing crop yields.[17]

IPCC Special Report on the Ocean and Cryosphere in a Changing Climate

In September 2019, the UN IPCC released the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) as part of the Sixth Assessment Report Cycle.[18] The SROCC offers a stark view of both current and future conditions of the oceans and cryosphere as we continue to emit large amounts of carbon into the atmosphere. The prognosis if we continue with business as usual is bleak; however, the report emphasizes that under a low emissions scenario, catastrophic impacts can be avoided.

The oceans and cryosphere directly or indirectly affect all people on Earth. Oceans cover 71% of the Earth's surface, while the cryosphere, or the frozen parts of the Earth's system, cover 10% of the Earth in the form of glaciers and ice sheets.[19] Coastal communities, small islands, polar zones and high mountains are at risk from changes such as sea level rise and melting glaciers and ice sheets. Communities further inland face threats from ocean changes through extreme weather events. The ecosystems of the oceans and cryosphere provide many services: the uptake of carbon dioxide and heat, supplying food and water, providing renewable energy, as well as tourism, trade, and transport. The SROCC states that the world is at or near critical tipping points that if passed, will trap the Earth into a positive feedback loop, leading to irreversible melting of ice sheets and further, catastrophic warming.

The SROCC covers observed changes, projected changes, and the implementation of responses to changes in the oceans and cryosphere. Observed changes to the oceans include increased warming,

[13] Ibid. at 2: Section A3
[14] Ibid. at 2: Sections B2-B6
[15] Ibid. at 2: Section B7
[16] Ibid. at 2: Section B3
[17] Ibid. at 2: Section A3
[18] IPCC, 2019: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate https://www.ipcc.ch/srocc/ (SROCC)
[19] Summary for Policymakers, SROCC

higher acidity, declining oxygen, disruption of fish species, more extreme storms, and increasingly frequent marine heat waves.[20] Melting ice sheets are now the primary driver of the sea level rise that threatens coastal communities with flooding. Coastal ecosystems are being damaged by climate change and human activity, weakening their ability to act as a buffer for sea level rise.[21] In polar and high mountain areas, snowpack is declining, which has threatened water supplies and led to increasing incidence of wildfires.[22]

Even if we were able to quickly and dramatically reduce GHG emissions, there are many locked-in changes projected to occur in the near future. These expected changes to coasts include higher sea level rise than was predicted in the IPCC's Sixth Assessment Report, which, without significant adaptation efforts, will lead to frequent and devastating coastal flooding.[23] In the Arctic, sea-ice free summers are more likely to occur, with far-reaching impacts on Arctic shipping and global trade, ecosystems, and coastal communities.[24] In the high mountain regions, snowpack decline will significantly threaten economies that rely on the ski industry.[25]

Continuing with business as usual will cause increasing ocean acidification and oxygen deprivation, the collapse of many fisheries, increasingly frequent and intense extreme weather, devastating sea level rise, and the loss of many biodiverse ecosystems. Thawing permafrost will release carbon into the atmosphere, accelerating the positive feedback loop of global warming. However, shifting to a low emissions pathway will dramatically reduce the aforementioned risks. The SROCC recommends shifting to ocean-based renewable energy sources to mitigate climate change and prevent catastrophic impacts on the oceans and cryosphere. It also calls for rapidly scaling up adaptation efforts to reduce the severity of impacts for marine ecosystems and Arctic and coastal communities.[26]

UNEP Emissions Gap Report 2019

The United Nations Environment Programme (UNEP) [27] released its tenth annual Emissions Gap Report (EGR) [28] in November 2019. The report provides an independent scientific assessment of the gap between anticipated carbon emission levels in 2030 and levels that would limit the rise of global temperatures to 1.5°C and 2°C over preindustrial levels. Prepared by 57 scientists from 33 expert institutions spanning 25 countries, the 2019 edition synthesizes the most current research into seven chapters organized around the key questions underpinning the 2018 Talanoa Dialogue, a product of the 23rd Conference of Parties (COP).[29] In the spirit of open discussion, the assessment

[20] Chapter 5, SROCC
[21] Chapter 4, SROCC
[22] Chapters 2 and 3, SROCC
[23] Chapter 6, SROCC
[24] Chapter 3, SROCC
[25] Chapter 2, SROCC
[26] Chapter 6, SROCC
[27] The United Nations Environment Programme (UNEP) is a separate entity from the United Nations Framework Convention on Climate Change (UNFCCC), though its work is closely tied to the latter's goals. The UNEP was founded in 1972 to coordinate UN efforts on sustainable development, climate, biodiversity, and other related fields. At the request of several member countries, the Emissions Gap Report was developed in 2010 to fill the need for an independent synthesis of emissions estimates, similar to the work of the IPCC. (https://www.unenvironment.org/resources/emissions-gap-report-2019)
[28] United Nations Environment Programme (2019). Emissions Gap Report 2019. UNEP, Nairobi. https://wedocs.unep.org/bitstream/handle/20.500.11822/30797/EGR2019.pdf?sequence=1&isAllowed=y
[29] The 23rd Conference of Parties (COP23) launched the Talanoa Dialogue, a mandated process aimed at increasing cooperation and facilitating dialogue between Parties in effort to build up to implementing the strongest possible emissions reduction commitments.

not only updates the status and projections of current global greenhouse gas emissions but also issues estimates of the drastic cuts required to comply with the Paris Agreement goals and bring warming down to within 1.5°C and 2°C.

The EGR details the acceleration of GHG emissions and thus, the increasingly difficult challenge of enacting the political and technical changes required to rein in emissions. Emissions show no signs of peaking, reaching a record high of 55.3 gigatons of carbon dioxide equivalents ($GtCO_2e$) in 2018, and bolstered by a 2.0 percent growth in fossil fuel emissions. This has created an estimated emissions gap of about 32 $GtCO_2e$ between current annual emissions and the track towards 1.5°C warming; instead, under current policies, global trends indicate an increase to annual emissions of 60 $GtCO_2e$. The EGR notes that developing countries use more energy per unit of economic activity than developed countries do; a critical difference as wealthier countries are increasingly outsourcing their carbon consumption to other countries in order to meet their own emissions goals.

The EGR specifically examines the performance of G20 nations[30] and finds that the United States is not on track to meet the 2010 Cancun Pledges, which formalized the emission reduction goals agreed upon in the Copenhagen Accord of COP15 into non-legally binding commitments.[31] Not only are significant actions required of the United States to meet its nationally determined contributions (NDCs)[32] set in the Paris Agreement, but, to stay within 1.5°C or 2°C of warming, the nation will have to set more stringent emissions targets. The EGR asks that developed nations like the United States lead the global charge towards emissions reductions, ideally towards a fundamental decarbonization of the global economy. Although the magnitude of this challenge is acknowledged, the authors also stress the multitude of co-benefits that could arise from such a shift. Solutions, such as the widespread expansion of renewable energy technologies, energy efficiency measures, and electrification of end uses, are emphasized as necessary to mitigation efforts. The authors also highlighted a few U.S.-specific policies identified to help meet the NDCs:

- Introduce regulations on power plants, clean energy standards and carbon pricing to achieve an electricity supply that is 100 percent carbon-free
- Implement carbon pricing on industrial emissions
- Strengthen vehicle and fuel economy standards to be in line with zero emissions for new cars in 2030
- Implement clean building standards so that all new buildings are 100 per cent electrified by 2030

[30] The G20 is an organization of the world's largest 20 economies and include: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, the United States and the European Union.
[31] https://unfccc.int/process-and-meetings/conferences/past-conferences/cancun-climate-change-conference-november-2010/cancun-climate-change-conference-november-2010-0
[32] The Nationally Determined Contributions refer to the voluntary Paris Agreement targets that each country set for themselves, based on the maximum each country believes is possible for themselves. These goals are essentially a reaffirmation of the Cancun Pledges. Each year, signatories are expected to report on their emissions and mitigation efforts, and continually revisit the targets for improvement.

ADDITIONAL READING

- International Cryosphere Climate Initiative, "Cryosphere1.5°: Where Urgency and Ambition Meet – Why Cryosphere Dynamics Must Mean 1.5° Pathways for 2020 NDCs," (2019) http://iccinet.org/wp-content/uploads/2019/12/Cryosphere1-5_191211a_high-res.pdf
- Ocean and Climate Platform, "Ocean and Climate Change: New Challenges – Focus on 5 Key Themes of the IPCC Special Report on the Ocean and Cryosphere," (2019) https://ocean-climate.org/wp-content/uploads/2019/12/fiches-EN-web.pdf
- International Union for Conservation of Nature and Natural Resources, "Ocean deoxygenation: Everyone's Problem – Causes, impacts, consequences, and solutions," (2019) https://portals.iucn.org/library/sites/library/files/documents/00%20intro%20DEOX.pdf
- Future Earth & The Earth League, "10 New Insights in Climate Science," (2019) https://futureearth.org/wp-content/uploads/2019/12/10-New-Insights-in-Climate-Science-2019.pdf

Chairwoman JOHNSON. This hearing will come to order. And without objection, the Chair is authorized to declare a recess at any time.

Let me say good morning and welcome to everyone, most especially our witnesses. This is our first hearing on the Committee on Science, Space, and Technology of the second session of the 116th Congress, and we're delighted that our experts have come and agreed to participate.

As was the case at our first hearing this Committee held in the 116th Congress, we are focusing on the climate crisis. Specifically, we are discussing the latest science and the solutions we urgently need to implement. Since that inaugural climate hearing in February 2019, I am proud to say that this Committee has held numerous hearings examining the climate crisis and moved a number of important climate-related bills through the Committee so far. The hearings have discussed major climate reports, considered technological and energy solutions, and assessed how the U.S. can remain a global leader in weather and climate science.

Members have been hard at work on a suite of legislative proposals that would improve our Earth system science and deep decarbonization efforts, including the authorization of strategic increases in funding for clean energy research and development where it's most needed. Despite these accomplishments, there remains more work to do to ensure that the United States can better understand, mitigate, and adapt to climate change.

Today, our expert witnesses will testify that time is quickly running out to prevent devastating impacts to humans and ecosystems globally. However, I hope they will also emphasize that though the situation is urgent, it is not hopeless. There is much we can achieve with our current technologies and other potential solutions ripe for further investment.

Climate change is not just a future issue. Our witnesses will testify about the real and devastating impacts that are being felt now in communities across the United States and the world. Record heat and drought in Australia, which current science links to human-caused climate change, have created catastrophic fires that continue to blaze. Though this Administration has so far abdicated its role as a leader in addressing the climate crisis, many of us in Congress are committed to addressing all aspects of this global threat.

Last month, a number of my colleagues and I attended the 25th U.N. Conference of Parties, or the COP 25, in Madrid, Spain. We went to demonstrate the U.S.' continuing commitment to the ideals laid out in the Paris Agreement.

While it was disappointing to see the outcome of the COP, I look forward to continuing our efforts to act on climate change here in this Committee and in Congress as a whole. During this second session, I hope to continue collaborating across the aisle to pass legislation that helps us address climate change, and this hearing is an important step in that process.

[The prepared statement of Chairwoman Johnson follows:]

Good morning. I'd like to welcome everyone here to the first hearing of the Committee on Science, Space, and Technology in the second session of the 116th Congress. I'd also like to welcome our expert witnesses and thank them for their participation. As was the case at the first hearing that this Committee held in the 116th Congress, we are focusing on the climate crisis. Specifically, we are discussing the latest science and the solutions we urgently need to implement.

Since that inaugural climate hearing in February 2019, I am proud to say that this Committee has held numerous hearings examining the climate crisis and moved a number of important climate-related bills through the Committee so far. The hearings have discussed major climate reports, considered technological and energy solutions, and assessed how the U.S. can remain a global leader in weather and climate science. Members have been hard at work on a suite of legislative proposals that will improve our earth system science and deep decarbonization efforts, including the authorization of strategic increases in funding for clean energy research and development where it is most needed.

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Chairwoman JOHNSON. Now, I'd like to enter into the record a letter from the National Parks Conservation Association. The letter briefly outlines the importance of science to national parks, especially in the reality of a changing climate.

I now will recognize our Ranking Member Mr. Lucas for his opening statement.

Mr. LUCAS. Thank you, Chairwoman Johnson.

As we start this second session of the 116th Congress, I want to thank you for your leadership. And like many of the hearings we held this last year, today's hearing is an opportunity for a constructive dialog on the issue of climate change.

Almost a year ago we held the Science Committee's first hearing of the Congress titled, "The State of Climate Science and Why It Matters." We heard testimony from a similar panel of IPCC (Intergovernmental Panel on Climate Change) authors and scientists.

We know the climate is changing, and that global industrial activity has played a role in this phenomenon. But now, 1 year later, I ask, what progress we've made since then? I believe my friends on the other side of the aisle agree with me that the most effective thing we can do on this Committee to address climate change is to support more basic research that will lead to the next generation of technologies that are needed to reduce global emissions like carbon capture, nuclear power, and fusion energy. I'm disappointed that we haven't taken that action, and instead of supporting the technologies of the future, we have focused our attention in the past year on applying research in industries like wind and solar that are already thriving.

I'm also disappointed in headlines that put a ticking clock on our destruction at the hands of climate change. This is counterproductive to promoting both science and solutions. These doomsday scenarios and apocalyptic predictions are misleading because the U.S. is already taking action through investments in the science and innovation needed for cleaner energy production.

We won't successfully address greenhouse gas emissions with pie-in-the-sky policies that demand 100 percent renewable energy at the expense of reliable power from nuclear and fossil fuels. This would only raise energy prices for businesses and consumers and potentially cripple the American economy.

Today, the market exists for implementing groundbreaking technologies. Government investment in basic research has led to the development of carbon capture, carbon use, advanced nuclear, and renewable energy technologies that will incentivize growth in these industries and reduce global emissions in the process. Innovation is good for the global environment and the American economy. We have to take the long-term approach and make investments in research that will lead to the new technologies.

Federal mandates to deploy today's technologies won't revolutionize the energy market. They won't lead to the next big discovery. For instance, the current U.S. battery capacity is just 1 gigawatt. If we were to meet the radical and, frankly, unrealistic goal of 100 percent renewable energy by 2050, we would need 3,300 gigawatts of battery capacity to accommodate the necessary solar and wind power. So if we want to see more renewable energy, we need to invest in the kind of fundamental chemistry and materials research that will lead to affordable, scalable batteries.

The Department of Energy (DOE) is developing a range of technologies at our national labs like carbon capture and advanced nuclear reactors that have the potential to reduce new greenhouse gas emissions around the world and ensure American energy dominance. It's unrealistic to limit our future energy mix to only renewable energy.

As we will hear from one of our witnesses, Mr. Michael Shellenberger, nuclear power is an incredible resource that is and will continue to be a critical piece of the puzzle in addressing climate change. Nuclear power is safe, clean, reliable, and growing more affordable by the day. Private companies are developing advanced reactors that provide clean, carbon-free power. With support from DOE, these advanced technologies could provide cheap, reliable, emissions-free power around the world. In order for this to happen, we can't let scare tactics allow us to abandon our promising technology.

America led the world in coal, oil, and gas. Now we must again lead and partner with industry to develop breakthrough energy technologies and make our existing energy sources cleaner and more affordable. Prioritizing investments in basic science and energy research will revolutionize the global energy market and dramatically reduce greenhouse gas emissions.

We have the tools and expertise to take on the next generation of technology challenges, including a changing climate. We have a common goal. I'm more encouraged than ever that we are on the right track. But I ask my colleagues, let's move on from the finger-pointing and focus on tangible innovation and realistic solutions.

I thank our witnesses for being here today, and I very much look forward to a productive discussion about these issues.

And with that, I yield back, Madam Chair.

[The prepared statement of Mr. Lucas follows:]

Thank you, Chairwoman Johnson. As we start the second session of this 116th Congress, I want to thank you for your leadership. Like many of the hearings we held last year, today's hearing is an opportunity for a constructive dialogue on the issue of climate change.

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I'm disappointed that we haven't taken that action, and instead of supporting the technologies of the future, we have focused our attention in the past year on applied research in industries like wind and solar that are already thriving.

I'm also disappointed in headlines that put a ticking clock on our destruction at the hands of climate change. This is counterproductive to promoting both science and solutions.

These doomsday scenarios and apocalyptic predictions are misleading—because the U.S. is already taking action through investments in the science and innovation needed for cleaner energy production.

We won't successfully address greenhouse gas emissions with pie-in-the-sky policies that demand 100% renewable energy at the expense of reliable power from nuclear and fossil fuels. This would only raise energy prices for businesses and consumers and cripple the American economy.

Today, the market exists for implementing groundbreaking innovations. Government investment in basic research has led to the development of carbon capture, carbon use, advanced nuclear, and renewable energy technologies that will incentivize growth in these industries—and reduce global emissions in the process. Innovation is good for the global environment and the American economy.

We have to take the long-term approach and make investments in research that will lead to new technologies. Federal mandates to deploy today's technologies won't revolutionize the energy market, and they won't lead to the next big discovery.

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I thank our witnesses for being here today and I look forward to a productive discussion.

Chairwoman JOHNSON. Thank you very much. If there are other Members who wish to submit additional opening statements, your statements will be added to the record at this point.

At this time I'd like to introduce our witnesses. Our first distinguished witness is Dr. Pamela McElwee, an Associate Professor of Human Ecology in the School of Environmental and Biological Sciences at Rutgers. Dr. McElwee is the Interdisciplinary Environmental Scientist whose research focuses on ecosystem services and resource use in the context of environmental changes.

She was a lead author of the chapter 6 of the IPCC Special Report on Climate Change and Land on integrated response options and lead author for chapter 6 on biodiversity governance of the global assessment of the Intergovernmental Panel of Biodiversity and Ecosystem Services.

She received her Ph.D. in forestry and environmental studies and anthropology at Yale University.

Our second witness, Dr. Richard Murray, is Deputy Director and Vice President for Research at the Woods Hole Oceanographic Institution. Mr. Murray is a geochemist whose research focuses on interpreting chemical records of climate change, vulcanism, and tropical oceanographic processes.

He previously served as Director of the Division of Ocean Scientists at the National Science Foundation (NSF) and as a Co-Chair for the Subcommittee on Ocean Science and Technology as part of the Office of Science and Technology Policy (OSTP).

Dr. Murray received his Ph.D. from the University of California at Berkeley.

Our third witness, Dr. Heidi Steltzer, a Professor of Environment and Sustainability at Fort Lewis College in Colorado. Her research focuses on how environmental changes affect mountain watersheds and arctic ecosystems and their link to our wellbeing. She has spent 25 years conducting field studies in mountain and arctic hillslopes in Colorado, Alaska, Greenland, and China. She was a lead author for the chapter on high mountain areas in the IPCC Special Report on the Oceans and Cryosphere in our Changing Climate.

Dr. Steltzer earned her Ph.D. in ecosystem ecology from the University of Colorado in Boulder.

Mr. PERLMUTTER. Go Buffs.

Chairwoman JOHNSON. I knew I'd hear a voice.

Our fourth witness is Mr. Michael Shellenberger, Founder and President of Environmental Progress. Mr. Shellenberger has been an environmentalist and social justice advocate for over 25 years. He has worked to preserve California's redwood forests, an advocate for clean energy investment. He founded Environmental

Progress with the goals of lifting all people out of poverty and saving the natural environment.

Mr. Shellenberger graduated from the Peace and Global Studies program at Earlham College.

And our final witness is Ms. Taryn Fransen, a Senior Fellow in the Global Climate Program at the World Resources Institute (WRI). Ms. Fransen is an international climate policy expert who focuses on pathways and policies to limit climate change, including long-term strategies and nationally determined contributions under the Paris Agreement. She was a lead author of the United Nations' Environment Programme (UNEP) Emissions Gap Report.

She received her master's degree in Earth systems at Stanford University and is pursuing doctoral studies in Energy and Resources Group at the University of California at Berkeley.

As our witnesses should know, you will each have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When all of you have completed your spoken testimony, we will begin with questions, and each Member will have 5 minutes to question the panel. So we will start now with Dr. McElwee.

TESTIMONY OF DR. PAMELA MCELWEE, ASSOCIATE PROFESSOR OF HUMAN ECOLOGY, SCHOOL OF ENVIRONMENTAL AND BIOLOGICAL SCIENCES, RUTGERS, THE STATE UNIVERSITY OF NEW JERSEY

Dr. MCELWEE. Great. Thank you, Chairwoman Johnson, Ranking Member Lucas, and Committee Members for inviting me to speak today. My name is Pam McElwee, and I'm an Associate Professor at Rutgers University. My research focuses on human vulnerability to global climate change and the impact of policies for land-based mitigation. I served as one of nearly 100 authors of the IPCC Climate Change and Land Report and was invited here to speak to the findings of that report, and I'm doing so in my personal capacity.

IPCC reports serve as the most authoritative assessments of current climate science. The Land report is one of three special reports that have been completed in this assessment cycle, along with the 1.5° report that came out last year, the Oceans and Cryosphere report that my fellow witnesses will speak about as well.

So let me provide an overview of what the key findings from the Land report were. First, land is under growing pressure. Currently, human use directly affects more than 70 percent of the global land surface, encompassing all the things that we do from growing crops, producing timber, managing pastures, and sheltering ourselves. However, these activities are putting increasing pressure on land and biodiversity, including through land-based emissions of greenhouse gases. Further, the rising impacts of climate change are already visible in many of our terrestrial ecosystems, and changes in land use can in turn amplify these signals.

Second, land can be part of the solution. Luckily, there are multiple options to achieve better land stewardship and reduced emissions such as through sustainable land management, improved food systems, and conserving priority ecosystems.

However, the report's third and final key message is that land cannot do it all. There is a finite amount of land, and it's often under intense competition. There are limits to what land can do for us in terms of mitigation without incurring sustainability tradeoffs. And the land sector cannot fully make up for failing to tackle fossil fuel emissions elsewhere.

So let me put some of these points in a bit more context. Since the pre-industrial period, the land surface air temperature has risen nearly twice as much as the global average temperature, and it is now at more than 1.5° Celsius. These temperature changes create stresses on land ranging from impacts on livelihoods, biodiversity, human and ecosystem health, infrastructure, and food systems. In the U.S. our land systems are already feeling climate change impacts, including heat and drought, extending the wildfire risk season in California, and extreme rainfall events last spring in the midwest.

Additional emissions in the future will increase the impacts on land and ecosystems. The frequency and intensity of droughts are projected to increase both globally and in the United States, as are the frequency and intensity of extreme rainfall events. For forests, we expect to see increases in the intensity and frequency of wildfires. As we are seeing play out in Australia right now, warmer and drier conditions facilitate fires that spread over larger areas and are harder to contain.

Food security is also at risk. We already see food systems affected by heat, changing precipitation patterns, and more extreme events. Future climate changes are projected to result in crop yield declines, increased prices, reduced nutrient levels and quality, and supply chain disruptions. All of these risks to land systems escalate with increasing temperatures.

Yet despite these problems, we have a number of solutions that are ready and available for us to use and at low cost. Land is really the only major sector where we cannot only reduce emissions but offset emissions from other sectors as well, creating a tremendous opportunity for farmers, ranchers, and other land managers. For example, sustainable land-use both reduces emissions and degradation and helps us adapt to climate changes. Improvement in soil health will increase carbon sequestration, improve farm productivity, and can secure new revenue streams.

Reforestation and restoration are win-wins as well, providing both short-term positive economic returns and longer-term benefits in terms of adaptation and mitigation. Other nature-based solutions like conservation of critical ecosystems have the potential to provide significant climate mitigation impacts as well.

Improving our food production and consumption systems can also be a win-win if we focus on increased food productivity, improved distribution and access, better dietary choices, and reduced food losses and waste.

So I personally grew up in a small farm in eastern Kansas from a long line of farmers. I understand how much our rural economies love the land and cherish being part of our great agricultural economy. But the challenges they and we face are increasingly serious. Rapid reductions in anthropogenic greenhouse gas emissions across all sectors, including fossil fuels and land, would substantially reduce the negative impacts of climate change on ecosystems and people.

Thank you for having me here today.

[The prepared statement of Dr. McElwee follows:]

Statement of
Pamela D. McElwee
Associate Professor, Department of Human Ecology
School of Environmental and Biological Sciences
Rutgers University – New Brunswick

before the

Committee on Science, Space, and Technology
U.S. House of Representatives
January 15, 2020

I would like to thank Chairwoman Johnson, Ranking Member Lucas, and the members of the House Committee on Science, Space and Technology for inviting me to speak today to provide testimony based on the findings of the Intergovernmental Panel on Climate Change (IPCC) Special Report on climate change, desertification, land degradation, sustainable land management, food security and greenhouse gas fluxes in terrestrial ecosystems, more commonly known as the Special Report on Climate Change and Land (SRCCL). In response to the request of the Committee, this testimony addresses the major findings of the SRCCL report and the implications for the United States, some remaining research gaps, and recommendations for steps that Congress can take toward potential solutions.

I am an associate professor of human ecology at Rutgers University, and served as one of several US scientists on the SRCCL report.[1] The IPCC solicits lead author nominations by member governments and observer organizations, and the final selection of report authors is determined by the IPCC based on these nominees, guided by a set of criteria that aims to balance diversity in scientific disciplines, as well as ensuring geographic and gender balance. Nearly 100 scientists from around the world served as a Coordinating Lead Author, Lead Author, or Review Editor for the SRCCL report. All these scientists volunteer their time without compensation for what is a very challenging and demanding process of preparing this comprehensive report. Although I participated closely in this process, and have received feedback on this testimony from some fellow IPCC authors, I am speaking on my own behalf and not for the IPCC or Rutgers University.[2]

IPCC reports serve as the most authoritative assessments of current climate science. The reports are based on a thorough assessment of all scientific literature, following strict guidelines as to what can and should be reviewed. The IPCC does not produce 'new' research per se, but rather

[1] The other authors representing the United States who are listed as authors of the Summary for Policymakers in the SRCCL report in addition to myself include: Dr. Katherine Calvin (Pacific Northwest National Lab), Dr. Cynthia Rosenzweig (NASA Goddard Institute for Space Studies/Columbia), Dr. Elena Shevliakova (NOAA Geophysical Fluid Dynamics Laboratory/Princeton), Dr. Koko Warner (UN Framework Convention on Climate Change), and Dr. Louis Verchot (International Center for Tropical Agriculture). Several other US-based scientists were involved with specific chapters as Lead Authors, Contributing Authors, or Review Editors.

[2] I would like to particularly thank the following authors from the SRCCL report who provided feedback on this testimony, although I alone am responsible for the statements herein: Almut Arneth, Katherine Calvin, Nathalie de Noblet-Ducoudré, Minal Pathak, Cynthia Rosenzweig, Elena Shevliakova, Pete Smith, Koko Warner, and Louis Verchot.

analyzes and synthesizes the thousands of scientific papers produced each year around different aspects of climate science.

The SRCCL report is one of three "Special Reports" completed in what is known as the 6th Assessment Cycle of the IPCC. These special reports are specifically requested by member governments of the IPCC to address specific research questions outside the traditional scope of the major Assessment Reports (AR) that the IPCC regularly produces. The Special Reports included in this cycle are: Global Warming of 1.5°C (SR15), Climate Change and Land (SRCCL), and the Ocean and Cryosphere in a Changing Climate (SROCC) report. All IPCC reports and summaries are subject to multiple rounds of review, and the summary for policymakers is approved word by word by member governments. The SRCCL was approved by all member governments, including the US, in a plenary in August 2019 in Geneva.

Key Findings: State of Science on Land and Climate

Let me provide an overview of what the key findings from the SRCCL report were, as summarized in the release of the report last August:

- *Land is under growing pressure:* Human activities affect 70% of ice-free land areas, of which 25% are experiencing human-caused degradation. The increasing impacts of climate change are visible in many of our terrestrial ecosystems, and changes in land use in turn can amplify these signals. How we manage land must be on the table in any discussion of responding to climate change.

- *Land is part of the solution*: Luckily, there are multiple options to achieve better land stewardship and reduced greenhouse gas (GHG) emissions, such as through sustainable production, reduced food loss and waste, healthy diets, and conserving priority ecosystems. Land is a hugely important sink for anthropogenic CO_2 emissions and we need to ensure it continues to supply us with this free subsidy from nature.

- *Land cannot do it all.* However, while sustainable land management can help reduce the loss of biodiversity while meeting food security needs and storing carbon, there is a finite amount of land and it is often under intense competition. There are limits to the scale of bioenergy crops and afforestation that can be used for climate mitigation without incurring sustainability trade-offs, so we need to make smart choices.

To put these conclusions in context, land is fundamental to human civilization. Land provides the principal basis for human well-being, including the supply of food, access to freshwater, and multiple other ecosystem services, which have been valued at approximately equivalent to the annual global Gross Domestic Product.[3] Current human use directly affects more than 70% of the global, ice-free land surface, encompassing all the things we do on land: grow crops, produce timber, manage pastures for livestock, and shelter ourselves in homes and cities, among other activities.

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[3] Costanza, R. et al. 2014. Changes in the global value of ecosystem services. *Global Environmental Change* 26: 152-158.

However, the SRCCL report identified that our activities on land have contributed to increasing net GHG emissions, loss of natural ecosystems (including forests, savannas, grasslands and wetlands in particular), and declining biodiversity. These findings complement those of the IPBES Global Assessment also released last year, for which this committee held a hearing in June 2019, and for which I also served as a lead author.[4] The reinforcing findings of these two reports show that we need to rethink our relationship with land in fundamental ways if we want to achieve the global goals of climate mitigation, adaptation and sustainable development.

Land plays a hugely important role in the climate system: Land is both a source and a sink of GHGs at the global level. It also plays a key role in the exchange of energy, water, and aerosols with the atmosphere, contributing to local and regional climatic changes that are important for human activities. Agriculture, Forestry and Other Land Use (commonly known as AFOLU) activities accounted for around 13% of CO_2 emissions, 44% of methane (CH_4), and 82% of nitrous oxide (N_2O) emissions from human activities globally during 2007-2016.[5] The CO_2 emissions are largely from deforestation, while the non-CO_2 gases are largely from crop and livestock production. These sources represent 23% of total anthropogenic emissions of GHGs over that time period. However, these emissions were also partially offset by removals due to afforestation, reforestation, and other land use activities, equivalent to 29% of total CO_2 emissions.

Emissions of all GHGs from agricultural production are projected to increase into the future, driven by population and income growth and changes in consumption patterns. Over the past several decades, CH_4 and N_2O emissions from land-based sources have risen faster than CO_2 from AFOLU sources. Enteric fermentation from the digestive processes of an increasing number of ruminant animals and the expansion of rice cultivation are important contributors to methane increases. Anthropogenic N_2O emissions from soils are a result of excess or inefficient nitrogen fertilizer application, and there has also been a major growth in emissions from managed pastures. For CO_2 emissions, tropical deforestation in particular remains a concern, as intact tropical forests store and sequester large amounts of atmospheric carbon, and these functions can be disrupted by clearing and disturbance such as fires.[6] We have been seeing such dramatic fires in Brazil and Australia recently, which not only release CO_2 in the short-term, but which may have a long-term impact on forests' ability to recover and retain their sink functions.

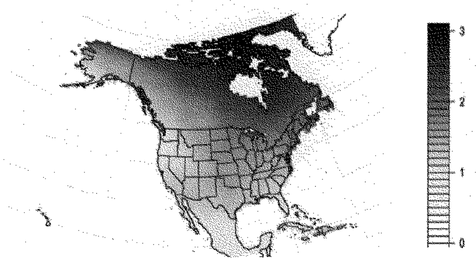
Land is already experiencing the impacts of climate change: All of these emissions contribute globally to rising temperatures, which in turn are experienced on land in different ways around the world. Changes in land conditions, either from land-use or climate change, affect both global

[4] Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 2019. *Summary for policymakers of the global assessment report on biodiversity and ecosystem services* [S. Díaz et al., eds.]. Bonn, Germany: IPBES Secretariat.
[5] This is equivalent to net CO_2 emissions of 5.2 ± 2.6 $GtCO_2$ yr-1 from land use and land-use change during the period of 2007-2016; Jia, G., E. Shevliakova, et al. 2019. Page 151 in Ch 2: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.
[6] Maxwell, S., et al. 2019. Degradation and forgone removals increase the carbon impact of intact forest loss by 626%. *Science Advances* 5 (10): eaax2546.

and regional climates. At the regional scale, changing land conditions can reduce or accentuate local/regional anthropogenic warming, even affecting temperature and rainfall in regions as far as hundreds of kilometers away. Regional land use changes (such as deforestation) can also affect the intensity, frequency and duration of extreme events, ranging from heat waves to droughts. At the global scale, emissions of GHGs from land-use activities, together with changes in land albedo, are drivers of climatic change.[7] In other words, how we use land at different scales can help us manage climate change, or it can make things worse.

Since the pre-industrial period, the land surface air temperature has risen nearly twice as much as the global average temperature, and is now at 1.53°C (2.7 °F) above preindustrial temperatures.[8] These global averages can, however, mask significant local variations (See Figure 1 for trends until 2015). The release this month of the State of the Climate assessment from NOAA confirms that in 2019 in the contiguous U.S. the average temperature was 0.7°F above average, while Alaska experienced its warmest year on record with a statewide average temperature of 6.2°F above the long-term average.[9]

Figure 1. Land air surface temperature increase in °C from preindustrial (1850-1900) to present (2006-2015)[10]



Temperature observations: *Berkeley Earth Surface Temperature dataset, Rohde et al. 2013*

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[7] Jia, G., E. Shevliakova, et al. 2019. Pages 144-150 in Ch 2: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.
[8] Ibid, page 142.
[9] NOAA National Centers for Environmental Information, *State of the Climate: National Climate Report for December 2019*, published online January 2020, retrieved on January 8, 2020 from https://www.ncdc.noaa.gov/sotc/national/201912.
[10] The Berkeley Earth Surface Temperature dataset provides land surface air temperature from 1750 to present based on almost 46,000 time series and has the longest temporal coverage of the four datasets used in the SRCCL report. See Rohde R., et al. 2013. A new estimate of the average earth surface land temperature spanning 1753 to 2011. *Geoinfor Geostat: An Overview* 1: 1. Map is courtesy of Dr. Elena Shevliakova, NOAA/Geophysical Fluid Dynamics Laboratory.

These global temperature changes create stresses on land, which the SRCCL report details, including exacerbating risks to livelihoods, biodiversity, human and ecosystem health, infrastructure, and food systems. Global warming has led to shifts of climate zones in many regions, including expansion of arid climate zones and contraction of polar climate zones. As a consequence, many plant and animal species have experienced changes in their ranges, abundances, and shifts in their seasonal activities.[11]

At our current levels of global warming we are already experiencing moderate risks from increased dryland water scarcity, soil erosion, vegetation loss, wildfire damage, permafrost thawing, coastal degradation and tropical crop yield decline. We are increasingly confident of being able to determine with specificity how extreme climate events like storms and floods are attributable to or exacerbated by climate change, a field known as "detection and attribution", which can reveal the fingerprint of anthropogenic change.[12] We know that existing warming has resulted in an increased frequency, intensity, and duration of heat-related events, including heat waves in most land regions, and such events can stress crops, disrupt pollination, and cause severe and often fatal human health impacts. Frequency and intensity of droughts has increased in some regions (including the Mediterranean, west Asia, many parts of South America, much of Africa, and northeastern Asia) and there has been an increase in the intensity of heavy precipitation events at a global scale.[13]

Further GHG emissions will increase the pressure on land and ecosystems: Increasing impacts on land are projected under all future GHG emission scenarios. Some regions will face higher risks, while some regions will face risks previously not anticipated, or cascading risks with impacts on multiple systems and sectors.[14] Climate zones are projected to further shift poleward in the middle and high latitudes, and in tropical regions, under medium and high GHG emissions scenarios, warming is projected to result in the emergence of unprecedented climatic conditions by the second half of the century. With this increasing warming, the frequency, intensity and duration of extreme heat events are projected to increase. The frequency and intensity of droughts are projected to increase as well, globally in the Mediterranean region and southern Africa, and in the US, in the Southwest and central regions.[15] The frequency and intensity of extreme rainfall events are also projected to increase in many regions.[16]

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[11] Jia, G., E. Shevliakova, et al. 2019. Page 143 in Ch 2: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.
[12] Sippel, S., et al. 2020. Climate change now detectable from any single day of weather at global scale. *Nature Climate Change* 10: 35–41.
[13] Jia, G., E. Shevliakova, et al. 2019. Pages 146-7 in Ch 2: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.
[14] IPCC. 2019. Summary for Policymakers, p. 15. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.)]. Geneva: IPCC.
[15] Jia, G., E. Shevliakova, et al. 2019. Section 2.5.1. in Ch 2: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.
[16] Hoegh-Guldberg, O., et al. 2018. Impacts of 1.5°C Global Warming on Natural and Human Systems. In: *Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels*

Projected future land impacts from climate change will occur in a range of ecosystems, including forests, savannas, coastal systems and agricultural lands.[17] For forests, future projections include continued increases in the intensity of wildfires and pest outbreaks, potentially leading to forest dieback conditions in some areas, and in high-latitude regions, boreal forests are at particular risk.[18] While aggressive fire control measures in the past decades have been able to globally diminish total fire outbreaks, the climate suitability for fire will continue to increase, and with it, wildfire risks. As we are seeing play out in Australia right now, warmer and drier conditions facilitate fires that spread over larger areas and are harder to contain. There is potential for fire frequency to increase over substantial portions of the global land area in the next two decades.[19] There is also strong evidence to link increased forest fire frequency in North America over 1984–2015 to increasing fuel aridity that is a result of anthropogenic climate change; these conditions have doubled the western USA forest fire area compared to what we would expect without these impacts.[20] All of these conditions put extreme stress on our forests, and the many species who live within them.[21]

Climate change also exacerbates land degradation, particularly in low-lying coastal areas, river deltas, drylands, and in permafrost areas; this happens through changes in rainfall intensity, flooding, drought frequency and severity, heat stress, dry spells, wind, sea-level rise and wave action, and permafrost thaw.[22] Over the period 1961-2013, the annual area of drylands in drought has increased on average by more than 1% per year, and in 2015, about 500 million people lived within areas that had experienced desertification. In the US, the Southwestern region has experienced decreases in vegetational activity (e.g. browning).[23]

Food security is particularly at risk from climate change: Climate change has already affected food security due to warming, changing precipitation patterns, and greater frequency of some extreme events. Some crops do respond to CO_2 fertilization with increased yields, but these are often offset by water and heat stress at higher temperatures. Many staple crops, such as wheat,

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and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., et al. (eds.)]. Geneva: IPCC.
[17] Ibid.
[18] Seidl, R., et al. 2017. Forest disturbances under climate change. *Nature Climate Change* 7: 395–402, doi:10.1038/nclimate3303.
[19] Moritz, M.A., et al. 2012. Climate change and disruptions to global fire activity. *Ecosphere*, 3(6), art49, doi:10.1890/es11-00345.1.
[20] Abatzoglou, J.T. and A.P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences*, 113(42), 11770–11775, doi:10.1073/pnas.1607171113.
[21] Lewis, D. 2020. 'Deathly silent': Ecologist describes Australian wildfires' devastating aftermath. *Nature* (10 Jan): *doi: 10.1038/d41586-020-00043-2*
[22] IPCC. 2019. Summary for Policymakers, p. 8. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.)]. Geneva: IPCC; IPCC. 2019. Summary for Policymakers, p. 16. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, et al (eds.)]. Geneva: IPCC.
[23] Jia, G., E. Shevliakova, et al. 2019. Section 2.3.4. in Ch 2: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.

corn, rice and soybeans, are projected to have reduced yields in the long run.[24] The tropics and subtropics are projected to be most vulnerable to crop yield decline; in many lower-latitude regions, yields of some crops (e.g., corn and wheat) have already declined, while in many higher-latitude regions, yields of some crops (e.g., corn, wheat and sugar beets) have increased in recent decades. Climate change has also resulted in demonstrably lower animal growth rates and productivity in pastoral systems in regions such as Africa.

There is also increasing evidence that higher atmospheric CO_2 levels can lower the nutritional quality of crops through changes in micronutrients; such micronutrient deficiencies already affect over 1.5 billion people. Higher CO_2 concentrations increase photosynthesis in certain plants (including wheat, rice, potatoes, and barley), but field studies simulating future growing conditions show that these crops have lower nutritional quality as plants accumulate less minerals (particularly iron and zinc), which can negatively affect human nutrition.[25] These deficiencies are not made up by technological improvements or market expansions in modelling studies.[26] Other concerns about the food supply under climate change include worries about increases in contaminating organisms such as mycotoxins, bacteria and enteric microbes (like salmonella) that can enter the human food chain. Degradation and spoilage of products in storage and transport can also be affected by changing humidity and temperature, notably from microbial decay, which can lead to reduced food quality and affect availability.

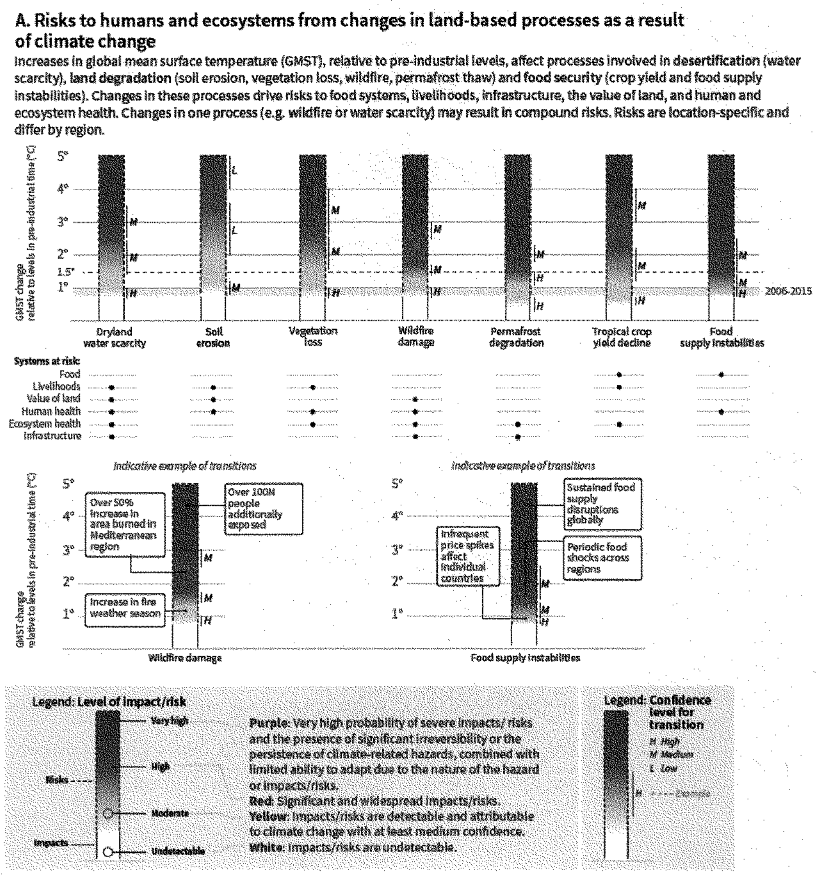
The stability of food supply is projected to decrease in the future under climate change, as the magnitude and frequency of extreme weather events that disrupt food chains increases. The potential for multi-breadbasket failure (that is, multiple crops in a region or across regions failing at once) increases at higher temperatures as compound events may occur.[27] In future scenarios, global crop and economic models project increases in cereal prices by 2050 due to climate change, leading to higher food prices and increased risk of food insecurity and hunger. The most vulnerable people (the poor, women and children, and those in stressed regions) will be more severely affected.[28]

Risks to land systems increase with temperature rise: All these risks are projected to become more severe with increasing temperatures. At around 1.5°C of global warming the risks from dryland water scarcity, wildfire damage, permafrost degradation and food supply instabilities are projected to be high. At around 2°C of global warming the risk from permafrost degradation and food supply instabilities are projected to be very high. Additionally, at around 3°C of global warming risk from vegetation loss, wildfire damage, and dryland water scarcity are projected to

[24] Zhao, C., et al. 2017. Temperature increase reduces global yields. *Proceedings of the National Academy of Sciences* 114 (35): 9326-9331.
[25] Myers, S., et al. 2014. Increasing CO_2 threatens human nutrition. *Nature* 510: 139–142.
[26] Beach, R., et al. 2019. Combining the effects of increased atmospheric carbon dioxide on protein, iron, and zinc availability and projected climate change on global diets: a modelling study. *The Lancet Planetary Health* 3 (7): e307-e317.
[27] Zscheischler, J., et al. 2018. Future climate risk from compound events. *Nature Climate Change* 8: 469–477.
[28] IPCC. 2019. Summary for Policymakers, p. 15. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.)]. Geneva: IPCC;

be very high. Risks from droughts, water stress, heat related events such as heatwaves and habitat degradation simultaneously increase between 1.5°C and 3°C warming (see Figure 2).

Figure 2. Risks to land based ecosystems[29]



The level of risk posed by climate change depends both on the level of warming and how population, consumption, production, technological development, and land management patterns continue to evolve. The SRCCL report uses scenarios known as Shared Socio-Economic

[29] Taken from figure SPM.2 of the SRCCL report. Please see SPM for discussion of the methods used to generate figure (p. 14-15)

Pathways (SSPs) to explore how these factors interact. In modelled pathways with higher demand for food, feed, and water, more resource-intensive consumption and production, and more limited technological improvements in agriculture, we see higher risks from water scarcity, land degradation, and food insecurity as a result. Development pathways in which incomes increase and the demand for land conversion is reduced, either through reduced agricultural demand or improved productivity, can lead to reductions in risks of food insecurity.[30] The SSP that reflects a highly cooperative open trade world with more sustainable consumption and lower population growth has a higher capacity to deal with higher temperatures than a divisive "go it alone" high-consumption world.

There are also the many indirect effects of changes in climate on human settlement and living patterns. For example, warming and associated changes in land productivity can amplify migration both within countries and across borders. Extreme weather and climate or slow-onset events may lead to increased displacement, threatened livelihoods, and contribute to exacerbating stresses for conflict.[31] In most cases, we see climate change as a threat multiplier of existing vulnerabilities, as it is difficult to separate out the direct impacts of climate alone. In some cases, social stress, conflicts and other human health impacts can contribute to destabilization of communities.[32]

Implications for the US

US land systems are already feeling climate change impacts: The SRCCL report was global in nature and did not focus on any particular country. For a more localized view of what the implications of the impacts and projections noted above mean for the US, the Fourth National Climate Assessment that came out last year is the gold standard, and for which this committee held a hearing in February 2019. In that report, the authors note that many of the trends that SRCCL has identified with global implications are also important in the US. For example, our agricultural lands, particularly in the Midwest, are likely to see more droughts, more heat, and more extreme rainfall events into the future.[33]

Several land-climate interactions in the US have been in the news recently. First, wildfires in California have brought much damage and lives lost in the past few fire seasons. To what degree are these driven by anthropogenic climate change? The evidence suggests that, as elsewhere, "human emissions have increased the probability that low-precipitation years are also warm" and

[30] IPCC. 2019. Summary for Policymakers, p. 15-16. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.)]. Geneva: IPCC

[31] Scheffran, J., and Battaglini, A. 2011. Climate and conflicts: the security risks of global warming. *Reg Environ Change* 11: 27–39.

[32] Sellers, S., et al. 2019. Climate change, human health, and social stability: Addressing interlinkages. *Environmental Health Perspectives* 127(4): 045002-1-045002-10

[33] USGCRP. 2018. *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., et al. eds.]. U.S. Global Change Research Program, Washington, DC. doi: 10.7930/NCA4.2018

it is the combination of drought and warm temperatures that create the conditions for which fires can spread.[34]

Second, floods in the Midwest this spring caused several billion US dollars' worth of damage and left 19 million acres unplanted.[35] We know that a warmer atmosphere holds more moisture, creating more potential for intense rainfall events and thus floods, which can be exacerbated by other land cover changes (e.g. deforestation, soil sealing). Yield variability of corn in particular in the Midwest is already noticeable and linked to rainfall extremes.[36] Interestingly, preliminary evidence suggests that farmers in the Midwest that were able to plant this spring were more likely to be ones who had had a higher average number of years with conservation tillage, no-till practices, and winter green cover.[37] In other words, proactive land conservation practices conferred adaptation benefits to farmers experiencing these extreme events.

The US is also vulnerable to increasing droughts in some areas, with particular impacts so far on species. In Colorado, drylands experiencing temperature changes have damaged biocrust communities with associated species loss, while in Southern California deserts climate change-driven extreme heat and drought may surpass the survival thresholds of some desert species.[38] Another related problem is the expansion of invasive species who thrive in warming climates at the expense of native ecosystems. For example, US sagebrush ecosystems have declined by nearly half since the late 1800s, and one major culprit is non-native cheatgrass (*Bromus tectorum*). Cheatgrass provides a fuel that increases the intensity, frequency and spatial extent of fires, severely impacting livestock producers, as grazing is not possible for several years after fire. Furthermore, cheatgrass and wildfires reduce critical habitat for wildlife, including vulnerable species like the greater sage-grouse.[39]

Land use contributes to overall US emissions, and there is room for emissions reductions: Here in the US, we also need to take stock of not just how our land and agriculture sectors might be impacted by climate change, but also understand the potential contributions of the sectors to both the problem and solutions. The EPA has estimated that the contribution of the agricultural sector is around 9% of total US anthropogenic emissions of CO_2, CH_4 and N_2O.[40] These land-based

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[34] Diffenbaugh, N. et al. 2015. Anthropogenic warming has increased drought risk in California. *Proceedings of the National Academy of Sciences* 112 (13): 3931-3936.
[35] USDA. 2019. Crop Acreage Data: https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index
[36] Jia, G., E. Shevliakova, et al. 2019. Section 2.3.5.4. in Ch 2: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.
[37] https://www.nature.org/content/dam/tnc/nature/en/documents/Dagan_Prevented_Planting.pdf
[38] Mirzabaev, A., J. Wu et al., 2019: Section 3.5.2. in Ch 3: Desertification. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.
[39] Mirzabaev, A., J. Wu et al., 2019: Section 3.7.3.4. in Ch 3: Desertification. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.
[40] This is lower than our global estimate in the SRCCL report of 23%, primarily because fossil fuel emissions in the US are proportionately higher, and our forest sector is a net sink. Source of emissions data and trends: US EPA,

emissions have been increasing in recent years, although at a slower rate than fossil fuel emissions. Half of these agricultural emissions relate to how we manage our soil, and one third relate to livestock production. Thus there are significant potentials for GHG emissions reductions in US agriculture and food processing, as well as a need to increase attention to adaptation options for these sectors.

Our forestry and land sector have resulted in net removals of CO_2 since 1990 in the US, and therefore serves as an important sink. However, between 1990 and 2017, total carbon sequestration by the land/forestry sector in the US actually decreased by 11.5 percent. This was primarily due to a decrease in the rate of net carbon accumulation in forests and croplands, as well as land conversion (primarily urbanization).[41] Therefore reversing this trend by looking for opportunities to increase carbon storage in our soils, grasslands, wetlands and forests is an important area for attention.

Further, some changes in how we grow biofuels in the US could also be of interest. The report notes that some models indicate that switching from annual crops to perennial plantations (such as *Miscanthus*) could lead to regional cooling due to increases in evapotranspiration and albedo, thereby somewhat counterbalancing warming trends. If we expanded perennial bioenergy across suitable abandoned and degraded farmlands, models show a near-surface cooling up to 5°C during the growing season.[42]

Looking for Solutions

Despite these problems, we have a number of solutions that are ready and available to use. *We do not need to wait for new scientific and technological breakthroughs for these to be implemented*; they are here now, and many are low cost. We can both reduce emissions from sources on land, as well as improve land's ability to act as a sink. The latter is particularly important if we want to reach net-zero emissions by 2050; that is, not all fossil-fuel emissions can easily be eliminated, so we need to offset those that cannot (e.g. airline emissions may be particularly difficult). Land can help us to achieve net-zero goals.

Sustainable land use reduces emissions and land degradation and helps us adapt: First, we need to use land more sustainably, both to reduce GHG emissions from the land sector and to reduce the impacts of existing climate changes. As a bonus, this can enable our lands to store more carbon as well, further reducing atmospheric CO_2. Sustainable land management (SLM) and policies promoting land degradation neutrality (LDN) can reduce the negative impacts of multiple stressors, and these are particularly important in many developing nations. Reducing and reversing land degradation, at scales from individual farms to entire watersheds, can provide cost effective, immediate, and long-term benefits to communities and support several Sustainable Development Goals (SDGs) with co-benefits for both adaptation and mitigation.

Inventory of US Greenhouse Gas Emissions and Sinks, 1990-2017. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

[41] Ibid.

[42] Jia, G., E. Shevliakova, et al. 2019. Section 2.7.1.5. in Ch 2: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.

While they can require upfront investment, many SLM technologies and practices are profitable within 3 to 10 years, as they can improve crop yields and the economic value of lands. SLM options that reduce vulnerability to soil erosion and nutrient loss include growing green manure crops and cover crops, crop residue retention, and reduced/zero tillage. Farming systems such as agroforestry, regenerative agriculture, precision agriculture, and use of perennial crops can substantially reduce erosion and nutrient leaching while building soil carbon. For example, experiments with Kernza grains show the potential of soil carbon increases through perennial grain production.[43] Other practices that provide both mitigation and adaptation benefits on croplands include erosion control, improved fertilizer management and integrated nutrient management, and use of adapted varieties for heat and drought tolerance.

Improvements in soil health, which increases carbon sequestration, can also improve productivity and secure new revenue streams for farmers. Soils that are carbon-rich are also more resilient to water stress or excess, and the USDA's existing working lands programs are a good example of how to help farmers meet goals of better soil health and land stewardship.[44] But there is always more demand for these than can be met at current funding levels, and only around 5% of US croplands receive funds under the two largest conservation programs.[45] Several farm and environmental organizations have supported adding 100 million acres of farmland into these programs, such as through increasing the Conservation Reserve Program acreage cap. Other potentially new ideas might include carbon storage rewards programs (e.g. price floors for sequestration) or voluntary or regulatory markets for soil carbon.

Land restoration is another important solution to provide both short-term positive economic returns and longer-term benefits in terms of climate change adaptation and mitigation, as well as biodiversity and enhanced ecosystem functions and services.[46] Restoration can result in benefit-cost ratios of between three and six in terms of the estimated economic value of restored ecosystem services in drylands in particular. Restored lands are more resilient to extreme events, which can buffer economic losses as well, and they also store more carbon. For example, increasing woody plant cover in open rangeland ecosystems in Texas led to a 32% increase in

[43] Olsson, L., H. Barbosa, et al., 2019. Section 4.9.2. in Ch. 4: Land Degradation. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds]. Geneva: IPCC.
[44] These include Conservation Reserve Program (CRP), Conservation Stewardship Program (CSP), the Environmental Quality Incentives Program (EQIP), the Agricultural Conservation Easement Program (ACEP), and the Regional Conservation Partnership Program (RCPP).
[45] US Department of Agriculture. 2018. *Summary Report: 2015 National Resources Inventory.* Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1422028.pdf
[46] Hobbs R.J. 2017. Where to from here? Challenges for restoration and revegetation in a fast-changing world. *The Rangeland Journal* 39, 563-566.

aboveground carbon stocks.[47] Rehabilitation of abandoned or underused croplands is one option with strong potential.[48]

Sustainable forest management aimed at providing timber, fiber, biomass, non-timber resources and other ecosystem functions and services can lower GHG emissions and contribute to adaptation.[49] For example, the expansion of forests in the US in recent years helps offset continued deforestation elsewhere. Forests are very useful at dampening the impacts of extreme events, and play important roles in modulating local climate (e.g. more evapotranspiration means more energy taken from the soil and thus surface cooling). Preserving and restoring natural ecosystems such as peatlands, mangroves, wetlands and forests, along with biodiversity conservation measures, have the potential to make positive contributions to sustainable development, enhancement of ecosystem functions and services, and other societal goals. For example, in the US, preservation of coastal wetlands provides storm protection services estimated at a value of 23.2 billion USD yr^{-1}.[50]

Improving our food production and consumptions systems can be a win-win: Food production can be a big part of the solution as well, if we focus on increased food productivity, improved distribution and access, better dietary choices, and reduced food losses and waste, all of which can reduce demand for land conversion. Because beef, lamb and farmed shrimp have the highest GHG emissions and environmental footprint of many foods, reducing the emissions intensity of these products through either management practices or reduced demand can help.[51] Serious reductions can be made in the emissions contributions of the livestock sector on the order of at least 30 percent if producers adopted the practices applied by those with the lowest emission intensity.[52] Further scientific breakthroughs, such as use of special disruptors of methane production in ruminant stomachs, also have the potential to bring down emissions from this sector.[53]

Balanced diets featuring plant-based foods, such as those based on coarse grains, legumes, fruits and vegetables, nuts and seeds, and animal-sourced food produced in resilient, sustainable and

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[47] Mirzabaev, A., J. Wu et al. 2019: Section 3.3.3. in Ch 3: Desertification. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.
[48] Benayas, J., et al. 2007. Abandonment of agricultural land: an overview of drivers and consequences. *CAB Rev.* 2, 1–14; Xie, Z. et al. 2019. Conservation opportunities on uncontested lands. *Nat Sustain* in press: doi:10.1038/s41893-019-0433-9
[49] Lewis, S., et al. 2019. Restoring natural forests is the best way to remove atmospheric carbon. *Nature* 568 (7750): 25-28.
[50] Costanza, R., et al. 2008. The value of coastal wetlands for hurricane protection. *AMBIO A J. Hum. Environ.*, 37: 241–248.
[51] Poore, J and T. Nemecek. 2018. Reducing food's environmental impacts through producers and consumers. *Science* 360: 987–992.
[52] Gerber, H., et al. 2013. *Tackling Climate Change Through Livestock: A Global Assessment of Emissions and Mitigation Opportunities.* FAO, Rome.
[53] Hristov, A., et al. 2013. Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. *J. Anim. Sci.*, 91, 5045–5069, doi:10.2527/ jas2013-658; Maia, M., et al. 2016. The potential role of seaweeds in the natural manipulation of rumen fermentation and methane production. *Scientific Reports* 6: 32321. doi:10.1038/srep32321

low-GHG emission systems, present major opportunities for adaptation and mitigation while generating significant co-benefits in terms of human health. The good news is that diets that are better for the planet also better for our health. For example, "nuts, minimally processed whole grains, fruits, vegetables, legumes, olive oil, and fish are associated with significantly reduced mortality and/or reduced risk for one or more diseases."[54] Public health policies to improve nutrition, such as increasing the diversity of food sources in public procurement, financial incentives, and awareness-raising campaigns can all potentially influence food demand, reduce healthcare costs, and contribute to lower GHG emissions.

Additionally, around 25-30% of total food produced is lost or wasted, and from 2010-2016, global food loss and waste contributed 8-10% of total anthropogenic GHG emissions. The EPA says food waste and packaging account for 45% of materials sent to landfills in the US.[55] Options to reduce loss and waste across the supply chain globally include improved harvesting techniques, on-farm storage, infrastructure and transport, packaging, retail options, and education. Even small tweaks across a range of sectors, from more flexitarian diets to the use of food waste as feed for animal production, can add up to reduced demands for land, with one estimate of a reduction of up to 37% of the current agricultural area through a series of small aggregated actions.[56]

Policies that operate across the food system should aim to enable more sustainable land-use management, enhanced food security and low emissions trajectories. Diversification in the food system (e.g., implementation of integrated production systems and healthier diets) can also help adapt to and reduce the risks from climate change. Adaptation and enhanced resilience to extreme events impacting food systems can be facilitated by comprehensive risk management, including risk sharing and transfer mechanisms, agricultural diversification, and advance preparation for increasing supply chain disruption. Changes in our current subsidy regimes to promote less GHG-intensive foods, and increase production efficiencies, would also help reflect the costs of many of the environmental externalities within the food system.[57]

Improving conservation of natural ecosystems is important for both mitigation and adaptation: There is increasing evidence for the success of 'nature-based solutions' and 'natural climate solutions' in recent years, with some estimates concluding that these options can provide over one-third of climate mitigation needed between now and 2030 to stabilize warming to below 2°C in a cost-effective manner.[58] Some of our land-based mitigation solutions can have immediate impacts, including the conservation of high-carbon ecosystems such as peatlands, wetlands, rangelands, mangroves and forests. Examples that provide multiple ecosystem services and

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[54] Clark, M., et al. 2019. Multiple health and environmental impacts of foods. *Proceedings of the National Academy of Sciences* 116 (46): 23357-23362.
[55] US EPA. 2015. *Reducing Wasted Food & Packaging: A Guide for Food Services and Restaurants.* https://www.epa.gov/sites/production/files/2015-08/documents/reducing_wasted_food_pkg_tool.pdf
[56] Alexander, P., et al. 2019. Transforming agricultural land use through marginal gains in the food system. *Global Environmental Change* 57: 101932
[57] Mamun, A. et al. 2019. *Reforming Agricultural Subsidies for Improved Environmental Outcomes.* Washington DC: International Food Policy Research Institute.
[58] Griscom, B., et al. 2017. Natural climate solutions. *Proceedings of the National Academy of Sciences* 114 (44): 11645-11650.

functions, but which may take more time to deliver, include reforestation (preferably with local species adapted to local environments) as well as the restoration of high-carbon ecosystems, agroforestry, and the reclamation of degraded soils. However, some caveats do apply here: land-based options that deliver carbon sequestration in soils or vegetation do not continue to sequester carbon indefinitely. Trees do grow faster under higher CO_2 concentrations; however, the lifetime of trees may be shortened, meaning that the long-term sequestration effect is also affected.[59] When vegetation matures or when vegetation and soil carbon reservoirs reach saturation, the annual removal of CO_2 from the atmosphere declines towards zero. In other words, land-based options can be tricky, and do not cancel out the need to also simultaneously reduce fossil fuel emissions.[60] There is no magic get-out-of-jail free card for us.

However, there are big tradeoffs with some land-based mitigation options: We also have opportunities to use the land sector to make more aggressive mitigation cuts, but the SRCCL report cautions that these come with tradeoffs. There are limits to the deployment of land-based mitigation measures such as bioenergy crops or afforestation. Although it may not be widely recognized by the public, all assessed modelled pathways that limit warming to 1.5°C or well below 2°C *require* land-based mitigation and land-use change, with most including different combinations of reforestation, afforestation, reduced deforestation, and bioenergy crop plantations. Indeed, most mitigation pathways include *substantial* deployment of bioenergy technologies. Only a small number of modelled pathways limit warming to 1.5°C without high dependence on bioenergy and/or bioenergy with carbon capture and storage (BECCS) and other carbon dioxide removal (CDR) options.[61]

Afforestation, reforestation, and the use of land to provide feedstock for bioenergy (with or without BECCS), or for biochar can greatly increase demand for land conversion if applied at the scale necessary to remove several $GtCO_2yr^{-1}$ (that is, a scale of several millions of km^2 globally). For example, biomass feedstock for biofuels can compete directly with food production for land and water use.[62] Modelled pathways limiting global warming to 1.5°C use up to 7 million km^2 for bioenergy in 2050; the bioenergy land area needed is smaller in 2°C (0.4 to 5 million km^2) and 3°C pathways (0.1 to 3 million km^2). At large scales, we are likely to see adverse side effects for water scarcity, biodiversity, land degradation, desertification, and food security. These impacts are context specific and depend on the scale of deployment, initial land use, land type, bioenergy feedstock, initial carbon stocks, climatic region and management regime. If bioenergy is integrated into sustainably managed landscapes at appropriate scales and with best practices, we can ameliorate many of these adverse impacts.

Adaptation of our land systems to existing and future warming is also crucial: Finally, we also need to explicitly focus our solutions on adaptation to the global warming we are already

[59] Büntgen, U. et al., 2019. 'Limited capacity of tree growth to mitigate the global greenhouse effect under predicted warming', *Nature Communication* 10 (2171)
[60] Anderson, C.M., et al. 2019. Maximize natural climate solutions - and decarbonize the economy. *Science* 363, 933-934. doi: 10.1126/science.aaw2741.
[61] These non-bioenergy pathways have however even more reliance on rapid and far-reaching transitions in energy, land, urban systems and infrastructure, and on behavioural and lifestyle changes compared to other 1.5°C pathways.
[62] Slade, R., A. Bauen, and R. Gross, 2014. Global bioenergy resources. *Nature Climate Change* 4(2), 99–105, doi:10.1038/nclimate2097

experiencing and the warming that has already been committed to, unless dramatic action to reduce GHG emissions is taken quickly.[63] Adaptation actions that also bring mitigation benefits are ideal, and examples of these co-benefits for both mitigation and adaptation include increased food productivity, improved cropland management, improved grazing land management, improved livestock management, agroforestry, improved forest management, increased soil organic carbon content, better fire management, and reduced post-harvest losses.[64] However, adaptation practices that increase GHG emissions (such as subsidies that might reward land conversion) or mitigation that makes adaptation harder (such as widespread BECCS) will involve tradeoffs we should try to avoid.

Research Gaps

Below I identify a few research gaps that emerged from work on the SRCCL report, as well as my own experience in reviewing this area. Many of these research gaps were also identified in a draft USDA Climate Resilience Science Plan, not yet released to the public, but which contains an excellent list of research priorities across categories of climate impacts, mitigation, adaptation, decision-support, indicators and metrics, and coordinated action.[65] The below gaps are areas in which we can fill in some details with more research, but they by no means should stop us from continuing to take action; indeed, because we don't fully know how some of our ecosystems and social systems respond to climate stressors, that is all the more reason to take strong mitigative action now.

How will our land sinks respond to future warming? The natural sink response of land to human-induced environmental changes is important and resulted in global net removals of 29% of our anthropogenic CO_2 emissions during 2007-2016.[66] Future net increases in CO_2 emissions from vegetation and soils due to climate change (e.g. permafrost thawing) are projected to counteract any increased removals due to CO_2 fertilization and longer growing seasons (e.g. vegetation greening). Yet the balance between these processes is a key source of uncertainty for determining the persistence and future of the land-carbon sink. Some additional evidence beyond the SRCCL report suggests that tropical forests in particular are likely to diminish their sink function and become a net carbon source in the future, as a result of continued deforestation and impacts from climate change alters forests' ability to sequester carbon dioxide.[67] Further work in

[63] IPCC. 2018. Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., et al. (eds.)]. Geneva: IPCC.
[64] Smith, P. et al. 2019. Which practices co-deliver food security, climate change mitigation and adaptation, and combat land degradation and desertification? *Global Change Biology* in press DOI: 10.1111/gcb.14878; McElwee, P. et al. 2020. The impact of interventions in the global land and agri-food sectors on Nature's Contributions to People and the UN Sustainable Development Goals. Under review with *Global Change Biology*.
[65] USDA Climate Resilience Science Plan, draft of September 14, 2017
[66] This is of course offset by AFOLU emissions, giving a total net land-atmosphere flux that removed 6.0+/-2.6 $GtCO_2\ yr^{-1}$. See Table SPM.1 in: IPCC. 2019. Summary for Policymakers. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.)]. Geneva: IPCC.
[67] Mitchard, E. 2018. The tropical forest carbon cycle and climate change. *Nature* 559: 527-534.

this area is ongoing and will be important to clarify these processes and improve our scientific understanding of land-climate feedbacks.

How can we explain and deal with increases in methane emissions? We also need further research on understanding trends in methane emissions, particularly because methane is such a potent heat-trapping gas. Methane emissions come from both anthropogenic and natural sources, and the globally averaged atmospheric concentration of methane showed a steady increase between the mid-1980s and early 1990s, slower growth thereafter until 1999, a period of no growth between 1999-2006, followed by a resumption of growth in 2007. We need to know more about these trends, and if atmospheric methane has been increasing since 2007 as a consequence of climate change (such as the loss of sink functions) or of our direct emissions and if so, from what sectors? Currently extensive work is being conducted with robust debate to understand how these trends can be explained, such as through underestimated fossil fuel methane sources in the US.[68] Current preparations to launch a methane-monitoring satellite by the NGO Environmental Defense Fund will be an important source of data, but highlights the fact that we should have had more federal leadership in this area already. Wetlands, particularly in the tropics, are a hugely important part of this picture and we need more research and mapping of their role in these processes and how they are responding to climate and other land use changes. This is important because the rise in methane since 2007 has serious implications for achieving the targets of the Paris Agreement.[69]

How can we anticipate and prevent land-based climate 'tipping points'? There is also a great deal of concern about whether we are beginning to see signs of climate 'tipping points', where the rate of change of a system accelerates rapidly, often in unpredictable ways, often with self-amplifying effects. Some scientists have recently warned that we may see tipping points even at lower temperature thresholds, including Antarctic ice sheet melt or dieback of the Amazon forest, with potentially irreversible consequences.[70] Tipping points were addressed in all three of the IPCC special reports, and the US National Climate Assessment devoted a chapter to these 'potential surprises'[71] but there is much more we need to know through continued robust research on these trends and feedbacks. We also need better ways to understand the economic impacts of these low probability but high impact events. The presence of medium-term warning systems from which we can anticipate tipping points (for example, in terms of land degradation) would be very important to cope with these changes.

Social and economic research gaps: how to internalize externalities in socially acceptable and economically feasible ways? There are also a number of policy and social science research gaps,

[68] Schwietzke, S., *et al.* 2016. Upward revision of global fossil fuel methane emissions based on isotope database. *Nature* 538: 88–91; Alvarez, R. et al. 2018. Assessment of methane emissions from the U.S. oil and gas supply chain. *Science* 361 (6398): 186-188

[69] Nisbet, E. et al. 2019. Very strong atmospheric methane growth in the 4 years 2014–2017: Implications for the Paris Agreement. *Global Biogeochemical Cycles* 33(3): 318-342.

[70] Lenton, T. et al. 2019. Climate tipping points — too risky to bet against. *Nature* 575 (28 Nov): 592-595 https://www.nature.com/articles/d41586-019-03595-0

[71] Kopp, R.E., et al. 2017. Potential surprises – compound extremes and tipping elements. In: *Climate Science Special Report: Fourth Nation- al Climate Assessment, Volume I* [Wuebbles, D.J., et al. (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 411-429.

although these receive far less support and funding. Between 1990 and 2018, the natural and technical sciences received 770% more funding than the social sciences on climate, with only 0.12% of all research funding spent on the social aspects of climate change mitigation.[72] This is a particularly important gap as we look for socially acceptable and economically viable solutions around land use. For example, how policies like carbon taxes would result in land-based mitigation incentives are less well known than the potential impacts in the fossil fuel use sectors. Current bills before the Congress to incentivize farmers to adopt soil conservation practices and to provide tax credit to farmers and ranchers who store carbon on farm and rangelands would benefit from more analysis of social and economic impacts and barriers to effective policy implementation.[73] This has not stopped some groups from moving ahead, including an Ecosystem Services Market Consortium and private investors who hope to generate offset credits on a voluntary soil carbon market. Yet the results of research on land-based offsets shows that these can potentially undercut gains in other sectors by providing an 'out' to avoid concrete emissions reductions, and we need further work in this area.[74]

How can we improve modelling of socio-economic pathways and future climate impacts?
Finally, the models that we use to project social and economic changes in response to climate and other impacts can also be improved. For example, most modelled mitigation pathways exclude the impacts of climate change, so we have limited understanding within Integrated Assessment Models (IAMs) of how adaptation can alter pathways. Many policy choices that we might be able to make are also not easily reflected in such models.[75] Having more clear ideas of what works for adaptation, that are measurable in terms of mitigation, and that bring economic benefits could create an "atlas of best practices" to assist consumers, producers, local communities and state governments to help them in decision-making.

Many of these research gaps above can be tackled by our land-grant universities, like my home institution of Rutgers. We combine both high-level scientific research with practical applications and engagement with farmers, producers and consumers through agricultural extension services, 4-H, and other interactions. The Foundation for Food and Agriculture Research, the public-private partnership founded in the 2014 Farm Bill, can play a role in funding such research. Overall, improvements in partnerships of researchers, scientists and agencies around agricultural and ecosystem conservation practices and their environmental outcomes can promote learning, adaptive management, and innovation.[76] These partnerships can expand the measuring and monitoring of land use and climate change through the use of new information and communication technologies, and provide a one-stop-shop for research findings combined with ways to make results useful to local areas, including communities and landowners.

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[72] Overland, I and B. Sovacool. 2020. The misallocation of climate research funding. *Energy Research and Social Science* 62: 101349.
[73] Amundson, R and L. Biardeau. 2016. Soil carbon sequestration is an elusive climate mitigation tool. *Proceedings of the National Academy of Sciences* 115 (46): pp. 11652–11656
[74] Lovell, H., et al. (2009). Carbon offsetting: Sustaining consumption? *Environment and Planning A: Economy and Space, 41*(10), 2357–2379; Galatowitsch, S.M. 2009. Carbon offsets as ecological restorations. *Restoration Ecology* 17: 563-570.
[75] Burke, et al. 2016. Opportunities for advances in climate change economics. *Science* 352 (6283): 292-293.
[76] Briske, D. et al (2017). Assessment of USDA-NRCS Rangeland Conservation Programs: recommendation for an evidence-based conservation platform. *Ecological Applications* 27: 94–104.

Conclusions

In conclusion, the land sector is both threatened by, but can also potentially be a way to reduce many impacts of, climate change. The modelling done for the SRCCL report indicates that rapid reductions in anthropogenic GHG emissions across all sectors (that is, *both* fossil fuels and land) following ambitious mitigation pathways aimed at limiting warming to 1.5°C *would substantially reduce the negative impacts of climate change on land ecosystems and food systems.* On the other hand, continuing to delay climate mitigation and adaptation responses across sectors *would lead to increasingly negative impacts on land, including biodiversity and ecosystem loss, and reduce the prospect of global sustainable development.*

Improving the way we use and manage land can't fix all our problems, but it can contribute significantly to addressing the climate change problem and adapting our economies to new realities. *We cannot achieve our global objectives without dealing with land-based emissions, but taking action on land cannot be an excuse for not taking action on fossil fuels. We need to do both.* Delays will only make things worse, as the 1.5°C report pointed out clearly. Deferral of GHG emissions reductions until a later point in time will result in increasingly serious and more costly trade-offs. These include some irreversible losses in land ecosystem functions and services required for food, health, habitable settlements and production, leading to major economic impacts on many countries in many regions of the world.

Delays in avoiding or reducing land degradation and promoting ecosystem restoration risks long-term impacts, including rapid declines in productivity of agriculture and rangelands, permafrost degradation and difficulties in peatland rewetting. Once some of these ecosystems are gone, they are gone. Delaying action, as is assumed in high emissions scenarios, could result in not only irreversible impacts but have the potential in the longer-term to lead to substantial additional GHG emissions due to amplifying feedbacks from changing ecosystems.

Delayed action across sectors also leads to an increasing need for widespread deployment of land-based adaptation and mitigation options in the future, such as BECCS, with increasingly higher initial costs and long-term tradeoffs, including biodiversity loss and food insecurity. The higher temperatures get, though, the harder these options become to use, as there is decreasing potential for the array of these options and limitations to their current and future effectiveness. For example, the potential for some response options, such as increased soil organic carbon, decreases as climate change intensifies, as soils have reduced capacity to act as sinks for carbon sequestration at higher temperatures and with reduced soil moisture.[77]

Thus, acting now may avert or reduce risks and losses and generate benefits to society. Prompt action on climate mitigation and adaptation aligned with improved land management and sustainable development can reduce the risk to millions of people from climate extremes, desertification, land degradation, and food and livelihood insecurity. Thank you for allowing me to present this testimony today.

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[77] Green, J.K. *et al.* 2019. Large influence of soil moisture on long-term terrestrial carbon uptake. *Nature* 565: 476–479.

PAMELA D. McELWEE is an Associate Professor of Human Ecology at the School of Environmental and Biological Sciences, Rutgers University, New Brunswick, NJ. She is trained as an interdisciplinary environmental scientist, with a joint Ph.D. in forestry & environmental studies and anthropology from Yale University. She has authored more than 60 scientific papers, book chapters, and policy reports, as well as an award-winning book, *Forests are Gold: Trees, People and Environmental Rule in Vietnam* (U of Washington Press, 2016).

Dr. McElwee's research primarily focuses on vulnerability of households and communities to global environmental change, including climate change, biodiversity loss, and deforestation, as well as the impact of policies for conservation and development, including land-based mitigation to climate change and management of ecosystem services. Her research has been funded with grants from the National Science Foundation and MacArthur Foundation, and in 2019 she was named an Andrew Carnegie Fellow. She has served as a lead author for both the Intergovernmental Panel on Climate Change Special Report on Climate Change and Land (2019) and the Global Assessment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019). She has served as an editor or on advisory boards of the journals *Conservation Letters, Conservation and Society, The Lancet Planetary Health, One Earth, Current History,* and *Environment and Society: Advances in Research*.

Previously, McElwee was an assistant professor of global studies at Arizona State University, a postdoctoral fellow at Yale University, Confidential Assistant for Legislative and Public Affairs at the White House Office of Environmental Policy, a staffer for Senator Al Gore of Tennessee, and as a special assistant at the US Environmental Protection Agency. Dr. McElwee holds an undergraduate degree from the University of Kansas, where she was KU's first female Rhodes Scholar, and an MSc degree in Forestry from the Department of Plant Sciences at Oxford University in the UK. She grew up in eastern Kansas on a small farm, and currently lives in Metuchen, New Jersey with her husband and daughter.

Chairwoman JOHNSON. Thank you very much. Dr. Murray.

TESTIMONY OF DR. RICHARD MURRAY, DEPUTY DIRECTOR AND VICE PRESIDENT FOR RESEARCH, WOODS HOLE OCEANOGRAPHIC INSTITUTION

Dr. MURRAY. Chairwoman Johnson, Ranking Member Lucas, Members of the Committee, my name is Richard Murray. I'm the Deputy Director and Vice President for Research at the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts. We're the world's largest independent nonprofit ocean research institution and have nearly 1,000 staff dedicated to ocean science, engineering, and education. Thank you for the opportunity to address you today on behalf of the broader U.S. ocean science community.

I have three main takeaway points for you today. First, the ocean is central to Earth's climate and weather systems, as well as our economic growth and national security and must be included in any discussion regarding legislation and policy addressing the environmental changes we see today.

Second, we as a Nation must make bold and innovative investments in ocean observations because this quantitative data is essential in order to improve climate and weather predictions and our ability to make difficult decisions about how we manage the future.

Third, the integration of climate and weather modeling with risk assessment and risk management models is needed to help align climate and economic policies that have the potential for dramatic and positive effect on the U.S. for generations to come. All of this relies on increasing and improving the quality of data throughout the world's oceans.

You specifically requested that I address the 2019 IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. This extensively peer-reviewed document marks a milestone in IPCC reports because it assesses comprehensively the role of the ocean in our planet's climate system and identifies the many ways that a changing climate influences and is influenced by the ocean.

The IPCC reports the result of more than 100 scientists from 36 countries who reference nearly 7,000 scientific publications and addressed over 31,000 comments from reviewers. The language in the report is very carefully chosen to depict the level of scientific certainty in its findings. It states that the ocean is changing in fundamental and complex ways that should be of concern to even the most landlocked of us.

These findings document some basic truths. The ocean is warming, sea levels are rising, sea ice is disappearing, surface waters are becoming more acidic, and oxygen minimum zones within the ocean depths are expanding. Of increasing concern is that it appears that the rate at which these changes are taking place is accelerating. It is not linear, nor is it steady. The evidence is clearly indicating that human activity has played a significant role in these changes.

But much of what is happening in the ocean is occurring over the horizon, deep beneath the surface, and over long periods of time. As a result, it's difficult for humans to sense or to understand what is happening. Only through decades-long observations and a comprehensive look at the ocean's distant past, recorded in cores of ice from land and in sediment from the seafloor, have we come to understand the scope and nature of our changing planet. But it's not enough. We need to learn more about our oceans in places we've never been and for longer than we've ever been there.

The ocean drives the weather that helps put food on our tables and is a foundation of local, State, and regional economies that total billions if not trillions of dollars per year. And it's not just places near the shore that should pay attention. For example, studies show that floods throughout the Mississippi River Valley in 2019 as far north as Minnesota were directly tied to weather patterns originating in the waters of the Gulf of Mexico and the Pacific Ocean. So it is with good reason that we take notice of the IPCC report, particularly because its findings are based on the best available scientific data and conclusions.

Now, it troubles some folks that, alongside these findings, the conclusions often include levels of certainty or uncertainty, which is often perceived as a weakness of science. In fact, the opposite is true. Some of the findings have lower certainty because we need better observations. This shows where we should turn our attention in order to improve our understanding and decrease that uncertainty. This is a hallmark of the scientific process.

Ocean observations are expensive and difficult to make, particularly in places like the Arctic and the southern oceans. The ocean as a whole is vast, harsh, constantly changing. So what are we to do? We must invest in the infrastructure, technology, and instrumentation of ocean observations to help make the ocean transparent to us. To study the ocean, you have to go out onto it and down into it, which is something the ocean science community specializes in.

With your continuing support for ocean science, expanding observational capability, and for developing the engineering and technological means and workforce to achieve such capability, we can help address the challenges that face us and generate the best information possible to help inform private, public, and business cost-benefit decisions.

I thank you again for the opportunity to appear before you, and I look forward to your questions.

[The prepared statement of Dr. Murray follows:]

Prepared Statement of
Dr. Richard W. Murray

Before the House Science, Space, and Technology Committee
United States House of Representatives

An Update on the Climate Crisis: From Science to Solutions

Washington, D.C.
January 15, 2020

Introduction

I am providing this testimony in my capacity as Deputy Director and Vice President for Research at Woods Hole Oceanographic Institution (WHOI). Woods Hole Oceanographic, with six research departments, more than 40 centers and labs, and nearly 1,000 scientists, engineers, technicians, and staff, is the world's leading, independent non-profit organization dedicated to ocean research, exploration, and education. Prior to my position at WHOI, I was a professor at Boston University for 27 years and, from 2015-2018, I had the privilege to serve the National Science Foundation as the Director of the Division of Ocean Sciences. While at the NSF, my team and I oversaw an annual budget of about $370 million devoted to the research, education, and technology grant programs, as well as critical infrastructure, such as the Academic Research Fleet, Ocean Observatories Initiative, and Scientific Ocean Drilling. I was also involved with many other activities in marine policy with the Office of Science and Technology Policy that facilitated collaborations with NOAA, Office of Naval Research, NASA, BOEM, and other agencies. As such, the testimony I present here is based on my research and teaching experiences, my work with the federal government, and engagement with the ocean research and technology community writ large.

In my testimony, I hope to achieve the following:

1. Provide a summary of the key findings from the IPCC's Special Report on Ocean and Cryosphere in a Changing Climate (SROCC).

2. Describe some of the impacts of the environmental changes discussed in SROCC have for the security of U.S. economy and workforce, the quality of life for our citizens,

and national security, including with the renewed Great Powers Competition with China and Russia.

3. Make some specific recommendations for you to consider as you make decisions regarding investments in the scientific enterprise overall, and with regard to climate specifically.

4. Reinforce the following "take home messages":

- The ocean must be included in any comprehensive discussion of climate legislation and policy, as well as of economic and national security. It is the key driver of much of what we land-bound humans experience in our weather patterns; the relationships between food, water, and energy; and our economic and national defense.

- Building on previous accomplishments by you and your predecessors, we as a nation must make bold and innovative investments in the ocean observation enterprise so that we may increase quantification of key climate processes—heat, carbon, and freshwater budgets—and refine models and predictions to the degree required for our economic and social well-being. It will only be with significant advancements in data coverage and quality that we will truly be able to take advantage of the scientific and engineering capabilities of our nation to further our economic and social well-being.

- The societal value of ocean observations is directly tied to its relevance to policy-makers in formats that clearly indicate the level of scientific confidence in its credibility and the clarity of any subsequent analysis.

- The integration of climate and weather modeling with risk assessment and risk management models will help align climate policies with economic incentives and disincentives. These climate policies that you are considering have the potential for dramatic and positive effects on the U.S. for generations to come, and in order to get it right you will need the very best understanding of risk and uncertainty scientists can provide. To reduce those risks and uncertainties requires vastly strengthened ocean observations.

My focus here is on the oceans. While there are many areas in need of policy and fiscal attention to help address the challenges accompanying climate change, throughout my testimony I will focus on the need for a significantly enhanced ocean observation enterprise across scientific disciplines, geographic regions, and temporal and spatial scales in the ocean.

I want to be clear that the scientific ocean observation enterprise includes not only the infrastructure and technology necessary for the actual capture of data, but the synthesis and processing of data and its integration into climate, weather, and ocean models to advance our prediction and forecasting capabilities. It is ships, buoys, and satellites, and the shore-based infrastructure to support them. It includes high performance computers and people. It includes novel and innovative technological developments, including battery development and miniaturization. It includes artificial intelligence and machine learning. In essence, it includes everything that other scientific and technological sectors are wrestling with, yet done in the harsh and corrosive world of the ocean. The difficulties of the ocean environment in which we work are rivaled only by those of outer space.

For oceans and climate, there are numerous needs given the diversity of challenges and scientific disciplines, which spread across the physical, biological, chemical, and geologic sciences. At the highest level, many of these needs can be captured under the need to better understand the heat, carbon, and freshwater "budgets," where budget is a scientific term focused on the underlying processes driving these cycles. There are many individual scientific focus areas within each of these processes or budgets, and—similar to how Congress must deal with financial budgets—these scientific processes are interconnected.

For example, the future rate of sea level rise can only be understood if we understand the melting of icecaps and glaciers, how much the surface and depth of the ocean is warming since water expands as it warms, and how ocean circulation patterns influence both polar ice sheet melting as well as regional sea level rise. Similarly, ocean health is closely tied to biogeochemical processes, so to understand the rate of increasing ocean acidification and its impact on marine ecosystems—including fisheries and corals—we need to better understand how carbon cycles through the ocean and how heat impacts this process. There are important other benefits to increasing our comprehending of these scientific functionings such as being better able to understand the transportation of pollutants such as microplastics throughout the global ocean. Additionally, a thorough understanding of the carbon budget and the ocean's capacity to absorb carbon dioxide (and heat) is critical to improving our capacity to predict future atmospheric carbon dioxide concentrations under various greenhouse gas emission scenarios.

Summary of findings from the IPCC *Special Report on the Ocean and Cryosphere in a Changing Climate*

All people on Earth depend directly or indirectly on the ocean. It covers 71 percent of Earth's surface and contains 97 percent of the Earth's water. The ocean also supports unique habitats, many of them economically important, and hosts physical, chemical, biological, and geological processes that are integral components of the climate system through global exchange of water, energy, and many of the forms of carbon that exist in the Earth system.

The projected responses of the ocean to past and current human-induced greenhouse gas emissions and ongoing global warming include climate feedbacks, changes over decades to millennia that cannot be avoided, thresholds of abrupt change, and irreversibility. Human communities in close connection with coastal environments, small islands (including Small Island Developing States, SIDS), and polar areas are particularly exposed to ocean and cryosphere change, such as sea level rise and extreme events such as storm surge. The low-lying coastal zone is currently home to around 680 million people (nearly 10 percent of the 2010 global population) and is projected to reach more than one billion by 2050. SIDS alone are home to 65 million people around the globe. Other communities further from the coast are also exposed to changes in the ocean, such as through extreme weather events and shifting patterns of precipitation.

In addition to the role of the ocean and/or cryosphere within the climate system, such as the uptake and redistribution of natural and anthropogenic carbon dioxide (CO_2) and heat, the ocean provides to people worldwide food and water security, renewable energy, transportation, and benefits that support health and well-being, cultural identity, tourism, and trade.

Certainty and Uncertainty: "Calibrated Language"

The language in the report is very carefully chosen to depict the level of certainty of specific statements and I urge you to study this figure from the report itself before continuing with the rest of my testimony.

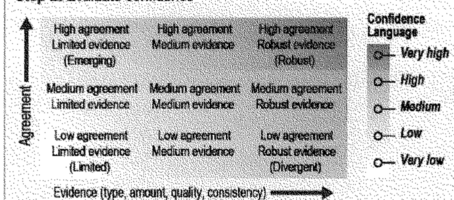
5

Step 1: Evaluate evidence and agreement

Observations ✔ Theory ✔ Statistics ✔ Models ✔ Experiments ✔ Process ✔

Sufficient evidence and agreement to evaluate confidence?

Step 2: Evaluate confidence



Examples

- Glacier retreat and permafrost thaw have decreased the stability of mountain slopes and the integrity of infrastructure (***high confidence***) {2.3}
- There is currently ***low confidence*** in appraising past open ocean productivity trends, including those determined by satellites, due to newly identified region-specific drivers of microbial growth and the lack of corroborating in situ time series datasets. {5.2.2}

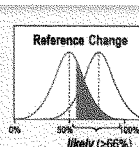
Sufficient confidence and quantitative/probabilistic evidence to evaluate likelihood?

Step 3: Evaluate statistical likelihood

Likelihood Language	Statistical Level (assessing change)	Statistical Range (assessing range)
Virtually certain	>99%	
Extremely likely	>95%	
Very likely	>90%	5–95% range
Likely	>66%	17–83% range
More likely than not	>50%	25–75% range
About as likely as not	33–66%	
Unlikely	<33%	<17% and >83% (both tails)
Very unlikely	<10%	<5% and >95% (both tails)
Extremely unlikely	<5%	
Exceptionally unlikely	<1%	

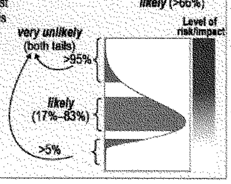
Example: statistical level

- Satellite observations reveal that marine heatwaves have ***very likely*** doubled in frequency between 1982 and 2016, and that they have also become longer-lasting, more intense and extensive. {6.4}



Examples: statistical range

- The AMOC will ***very likely*** weaken over the 21st century (*high confidence*), although a collapse is ***very unlikely*** (*medium confidence*). Nevertheless, a substantial weakening of the AMOC remains a physically plausible scenario. {6.7}
- Global mean sea level will rise between 0.43 m (0.29–0.59 m, ***likely range***) (RCP2.6) and 0.84 m (0.61–1.10 m, ***likely range***) (RCP8.5) by 2100 (*medium confidence*) relative to 1986–2005. {4.2.3}



Deep uncertainty (Cross-Chapter Box 5 in Chapter 1)

- Evolution of the Antarctic Ice Sheet beyond the end of the 21st century is characterised by ***deep uncertainty*** as ice sheet models lack realistic representations of some of the underlying physical processes. {Cross-Chapter Box 8 in Chapter 3}

As described more fully in the Special Report itself, like other IPCC reports the statements regarding changes in the ocean and cryosphere are assigned a quantitative statement of confidence or likelihood (e.g., "virtually certain", "exceptionally unlikely", etc.). This schematic demonstrates the IPCC usage of this calibrated language, with examples of confidence and likelihood statements from the report. You will immediately note that the Report's usage of phrases such as "very likely", "likely", or "high confidence" have far more meaning than when you or I use them when speaking casual English language to each other. This is a vitally important premise to consider when reading the report.

Findings

I would like to start this brief summary of the IPCC's Special Report on Ocean and Cryosphere with the following statement taken directly from Section B2 of the *Summary for Policymakers, Projected Changes and Risks*:

> *"Over the 21st century, the ocean is projected to transition to unprecedented conditions with increased temperatures (virtually certain), greater upper ocean stratification (very likely), further acidification (virtually certain), oxygen decline (medium confidence), and altered net primary production (low confidence). Marine heatwaves (very high confidence) and extreme El Niño and La Niña events (medium confidence) are projected to become more frequent. The Atlantic Meridional Overturning Circulation (AMOC) is projected to weaken (very likely)."*

This implications of this assessment and the relative confidence in the data supporting it is a sobering wake-up call about the important role the ocean plays in our planetary system. While it has been easier to ignore change in the ocean given that much of it occurs beyond our sight from land and also below the surface, mounting evidence of the impact the massive absorption of heat and carbon are having on physical, biological, chemical, and geological processes in the ocean indicates the ocean must be included in all considerations of weather and climate throughout the entire planet, including the deep interiors of continents very far from the oceans.

Perhaps the greatest benefit of this report is increasing recognition and public visibility of the ocean's role both driving and being driven by Earth processes and the changing climate. It pulls together in one document the physical, chemical, biological, and geological processes occurring in the ocean and along our coast and considers them in the context of a changing climate. The ocean, with its capacity to absorb and distribute vast amounts of heat and carbon on time scales that range from days to centuries to millennia, is at once the memory and the future of our climate.

Below are the key findings of the Special Report as they pertain to the ocean, which are compiled and summarized in the Summary for Policymakers. Rather than repeat their comments verbatim, I have encapsulated their main summary in straightforward points (albeit significantly shortened). The numbering system I use here (e.g., A1, A2, etc.) follows that of the Report, to assist further examination if you research beyond my abbreviated and heavily paraphrased presentation here. Further, it is important to explicitly point out that the High Level Findings summarized below are supported by multiple lines of evidence.

First, **What has been happening physically and chemically to the ocean?** As summarized in A1-A3 of the report, there have been significant decreases in the size and extent of ice sheets, glaciers, snow cover, and Arctic sea ice. Permafrost is thawing, as well. The ocean has warmed continually at least since 1970 and the rate of warming has doubled since 1993. Marine heatwaves are increasing in intensity and have very likely doubled in occurrence. Sea level is rising, and the rise is getting faster as more land-based ice melts and the oceans expand as they warm. Large storms are increasing in frequency and intensity, which further contributes to the impacts of sea level rise and increases in coastal and near-coastal hazards. Chemically, ocean acidification has increased and the upper ocean is losing oxygen.

Second, **What are the impacts on important ecosystems?** Focusing on the oceanic portion of this question (some impacts are more focused on the land and cryosphere, and thus I am not presenting here given the expertise of other witnesses), sections A5 and A6 document that since about 1950, many marine species across various groups have undergone shifts in geographical range and seasonal activities in response to changes in their habitats, including ocean warming, sea ice change and biogeochemical changes, such as oxygen loss. This has resulted in shifts in species composition, abundance and biomass production of ecosystems, and cascading impacts on ecosystem structure and functioning all the way from the equator to the poles. In some marine ecosystems species are affected by both fishing and climate change. Coastal ecosystems are affected by intensified marine heatwaves, acidification, loss of oxygen, salinity intrusion, and sea level rise in combination with adverse effects of human activities on ocean and land. Impacts are already observed on habitat quality and biodiversity, as well as ecosystem functioning and services.

How does this affect us? Again, focusing here on the oceanic portion of the report, sections A8 and A9 document that there have been both positive and negative impacts result for food security through fisheries, local cultures and livelihoods, governance, tourism, and recreation. The impacts on ecosystem services have negative consequences for health and well-being of all, including but not limited to Indigenous peoples and local communities dependent on fisheries. Coastal communities are exposed to multiple climate-related hazards, including tropical cyclones, extreme sea levels and flooding, marine heatwaves, sea ice loss, and permafrost thaw (high confidence).

What will the future look like? As presented in B1-B3, global-scale glacier mass loss, permafrost thaw, and decline in snow cover and Arctic sea ice extent are projected to continue in the near-term (2031–2050) due to surface air temperature increases, with unavoidable consequences for river runoff and local hazards. The Greenland and Antarctic Ice Sheets are projected to lose mass at an increasing rate throughout the 21st century and beyond. The rates and magnitudes of these cryospheric changes are projected to increase further in the second half of the 21st century if we live in a high greenhouse gas emissions scenario. However, if there are strong reductions in greenhouse gas emissions in the coming decades, further changes after 2050 may be reduced.

Over the 21st century, the ocean is projected to transition to unprecedented conditions with increased temperatures, greater upper ocean stratification, further acidification, decreasing oxygen, and perhaps altered net primary production. Marine heatwaves and extreme El Niño and La Niña events are projected to become more frequent. The Atlantic Meridional Overturning Circulation (AMOC) is projected to weaken. As with the cryospheric changes, the rates and magnitudes of these changes will be smaller under scenarios with lower greenhouse gas emissions.

Sea level continues to rise at an increasing rate. Extreme sea level events that are historically rare (once per century in the recent past) are projected to occur frequently (at least once per year) at many locations by 2050 in all emission scenarios, especially in tropical regions. The increasing frequency of high water levels can have severe impacts in many locations depending on exposure. Sea level rise is projected to continue beyond 2100 in all emission scenarios. Extreme sea levels and coastal hazards will be exacerbated by projected increases in tropical cyclone intensity and precipitation, and projected changes in waves and tides vary locally in whether they amplify or ameliorate these hazards.

What are the risks for ecosystems and humans? As summarized in B5-6, and B8-9, the changes are likely to be wide-ranging. A decrease in global biomass of marine animal communities, their production, and fisheries catch potential, as well as a shift in species composition, are projected over the 21st century from the surface to the deep seafloor under all emission scenarios. Ocean acidification, oxygen loss, and reduced sea ice extent, as well as non-climatic human activities, have the potential to exacerbate these warming-induced ecosystem impacts.

Risks of severe impacts on biodiversity, structure and function of coastal ecosystems are projected to be higher for elevated temperatures under high compared to low emissions scenarios in the 21st century and beyond. Projected ecosystem responses include losses of species habitat and diversity, and degradation of ecosystem functions. The capacity of organisms and ecosystems to adjust and adapt is higher at lower emissions scenarios. For sensitive ecosystems such as seagrass meadows and kelp forests, high risks are projected if global warming exceeds 2°C above pre-industrial temperatures, combined with other climate-related hazards. Warm-water corals are at high risk already and are projected to transition to very high risk even if global warming is limited to 1.5°C.

Future shifts in fish distribution and decreases in their abundance and fisheries catch potential due to climate change are projected to affect income, livelihoods, and food security of marine-resource-dependent communities. Long-term loss and degradation of marine ecosystems compromises the ocean's role in cultural, recreational, and intrinsic values important for human identity and well-being.

Increased average and extreme sea level, alongside ocean warming and acidification, are projected to exacerbate risks for human communities in low-lying coastal areas under higher emission scenarios, causing greater harm and presenting greater challenges than low emission scenarios. Ambitious adaptation including transformative governance is expected to reduce risk, but with context-specific benefits.

The report also includes a very relevant section regarding how to implement responses to these observed and predicted changes to the ocean and cryosphere (Section C). Much of this section is in the realm of "policy" and thus is not my purview here. However, virtually all of the implementation activities discussed in the report will strongly benefit, and have their chance of success greatly elevated, by increased scientific understanding of the ocean. I argue here that the overall approach of making bold and innovative investments in the ocean observation enterprise will be the most impactful way to achieve this goal.

For example, this section of the report discusses adaptation strategies and notes that "people with the highest exposure and vulnerability are often those with the lowest capacity to respond." I note, however, that investment in ocean science, engineering, and technology could help reduce this vulnerability. Coastal restoration, decreasing coastal pollution, managed retreat of our land-based communities and infrastructure, and all the other options being discussed, will benefit from enhanced ocean observations and an improved predictive capability.

Research Highlight: The ocean twilight zone

The ocean's mesopelagic, or twilight zone, is a poorly understood region of the ocean between 200 and 1,000 meters (650 and 3,300 feet) where sunlight is barely a glimmer and insufficient to support photosynthesis. Nevertheless, it is teeming with life—some estimates put the biomass of the twilight zone at 10 times that of the rest of the ocean combined. As a result, many commercial fishing interests are beginning to target the region as a way to meet demand for fishmeal drive by aquaculture.

The twilight zone is also a critical part of the biological carbon pump, which helps move carbon from sunlit surface waters, where photosynthesis turns carbon dioxide into organic carbon, down to deep waters, where it may be stored for hundreds or thousands of years. WHOI's Ocean Twilight Zone effort, funded by the Audacious Project at TED, is attempting to advance knowledge of the mesopelagic in an effort to provide policy-makers with the knowledge they need to ensure sustainable long-term management of this vital marine resource that balances its value as a food source with its role in the global carbon cycle.

Key Findings from Other Recent Peer-Reviewed Reports

The IPCC report is receiving a great deal of attention, which I believe is appropriate given what we see going on around us and the tremendous importance of the ocean to the weather-climate system, both now and in the future. There have been many reports from the U.S. government, international bodies, NGOs, and academics on different aspects of the ocean system over the years, and summarizing them all is not appropriate for this testimony. However, two recent noteworthy ocean focused reports released in 2019 are summarized below, because they present different yet consistent perspectives on the role and impact on the oceans.

Sustaining Ocean Observations to Understand Future Changes in Earth's Climate
National Academies of Sciences Ocean Studies Board Workshop Report (2017)
https://www.nap.edu/download/24919
In 2017, the National Academies Ocean Studies Board convened members of the earth and ocean sciences community to consider processes for identifying priority ocean observations that will improve understanding of the Earth's climate processes and the challenges associated with sustaining these observations over long time frames, as well as approaches for overcoming these challenges. Their findings are very insightful, and I highlight some of the most salient ones in Recommendations below. I will also present a more thorough summary of this report's findings as an appendix to this testimony.

Ocean Deoxygenation: Everyone's problem
International Union for Conservation of Nature (2019)
https://portals.iucn.org/library/sites/library/files/documents/2019-048-En-Summ.pdf
Working with 67 scientific experts representing 51 institutes in 17 countries, this report presents what to my knowledge is the largest peer-reviewed study conducted so far on ocean deoxygenation. Ocean deoxygenation is occurring at all depths due to lower solubility of oxygen in warmer waters, stronger vertical stratification (steeper temperature gradient) inhibiting diffusion of oxygen from the surface to the deep ocean, and more sluggish deep circulation that reduces oxygen supply to deep waters. Alongside this, increased nutrient inputs to the ocean through river runoff and from the atmosphere are promoting algal blooms, increasing oxygen demand and causing development of hundreds of coastal hypoxic (dead) zones in the ocean as well as intensification of naturally formed low-oxygen zones. According to the report:

- The global ocean oxygen inventory has decreased by about 2 percent over the period 1960 to 2010. One other specific study notes that in some tropical areas the oxygen content has decreased by 40 percent over the past 50 years (https://www.scientificamerican.com/article/the-ocean-is-running-out-of-breath-scientists-warn/).

- Model simulations project a decline in the dissolved oxygen inventory of the global ocean of 1 to 7 percent by the year 2100, caused by a combination of warming-induced decline in oxygen solubility and reduced ventilation of the deep ocean.

- Longer-term oxygen trends caused by climate change are masked by oxygen variability on a range of different spatial and temporal scales.

- The decline in the oceanic oxygen content can affect ocean nutrient cycles and the marine habitat, with potentially detrimental consequences for ecosystems, dependent people and coastal economies.

- Ocean oxygen loss is closely related to ocean warming and acidification caused by increasing carbon dioxide driven by anthropogenic emissions, as well as biogeochemical consequences related to anthropogenic fertilization of the ocean; hence a combined effort investigating the different stressors will be most beneficial to understand future ocean changes.

- It is predicted that there will be distinct regional differences in the intensity of oxygen loss as well as variations in ecological and biogeochemical impacts. There is consensus across models that oxygen loss at mid and high latitudes will be strong and driven by both solubility reductions and increased respiration effects.

The Ocean as a Solution for Climate Change: 5 Opportunities for Action
High Level Panel for a Sustainable Ocean Economy (2019)
(http://oceanpanel.org/sites/default/files/2019-10/HLP_Report_Ocean_Solution_Climate_Change_final.pdf)

The "High Level Panel" is a unique group of world leaders from around the globe committed to developing, catalyzing and supporting solutions for Ocean health and wealth in policy, governance, technology and finance. The report identifies five ocean-based climate action areas that can help in the fight against climate change. Full implementation of these ocean-based climate solutions could deliver one-fifth (up to 21 percent) of the annual greenhouse gas emissions cuts the world needs by 2050 to keep global temperature rise below 1.5 degrees Celsius. These are:

- *Ocean-based renewable energy*: Reduce barriers to scaling up offshore wind (fixed and floating turbines) and invest in new, innovative ocean-based energy sources such as floating solar photovoltaics, wave power, and tidal power.

- *Ocean-based transport:* Implement available technologies to increase energy efficiency now (e.g., improved hull design), and support the development of low-carbon fuels as part of a broader decarbonisation of ocean industries and energy supply chains, including port facilities. Start with decarbonising the domestic fleet, such as coastal ferries.

- *Coastal and marine ecosystems:* Conserve existing "blue carbon" ecosystems (mangroves, seagrass beds, and salt marshes) to prevent further release of GHG emissions and scale up restoration efforts. Expand farmed seaweed as an alternative fuel and feed source.

- *Fisheries, aquaculture, and dietary shifts:* Reduce the emissions intensity of fisheries and aquaculture operations through optimising wild catch and shifting to low carbon feed options. Shift diets toward low carbon marine sources such as sustainably harvested fish, seaweed, and kelp as a replacement for emissions intensive land-based sources of protein.

- *Carbon storage in the seabed*: Invest in the research necessary to minimize environmental impacts of long-term storage of carbon in the seabed and remove regulatory and economic barriers.

In addition, The High Level Panel has commissioned a series of "Blue Papers" (https://www.oceanpanel.org/blue-papers) to explore pressing challenges at the nexus of the ocean and the economy. These Blue Papers will summarize the latest science, and state-of-the-art thinking about innovative ocean solutions in technology, policy, governance, and finance realms that can help to accelerate a move into a more sustainable and prosperous relationship with the ocean. Sixteen Blue Papers are in development and will be released with regular cadence between November 2019 to June 2020.

I note that each of the above climate "action areas" will benefit greatly from increased investment by the U.S. Government in the overall enterprise of ocean science, engineering, and technology in the context of ocean observations. In the next section of my testimony here, I will present some of these investments to date, and point out their successes in the context of further future opportunities.

Research Highlight: Ensuring the future of coral reefs in a warming ocean

Coral reefs occupy barely one percent of Earth's surface, yet they host more than one-quarter of marine life, protect communities and coastlines from waves and storms, and support almost 1 billion people. They are the tropical ocean's most valuable ecosystem, yet their future is highly uncertain. Climate change, particularly ocean warming, has already killed thousands of square kilometers of reef around the globe and extinction potentially looms as ocean temperatures rise unabated.

Newly discovered "Super Reefs" have the ability to survive in a rapidly warming ocean. With tools and technologies that include autonomous underwater vehicles, hydrodynamic modeling, and genomic analysis, a team that includes Anne Cohen (WHOI) plus collaborators at Stanford and The Nature Conservancy are locating these extraordinary places, and uncovering their secrets. Some are genetically adapted to resist extreme heat; others are cooled by natural oceanographic processes. Super Reefs that survive will naturally restock neighboring regions and will provide the source to restock reefs worldwide.

Major Existing Ocean Observing Programs of Interest

In recent decades, the U.S. Federal Government has committed to supporting the transitional development of ocean observing systems. Many of these are also contributed to by the international community, either via direct pairing or by our international colleagues responding to U.S. leadership and spinning up parallel programs. Although the U.S. has much to be congratulated for, we are now facing the realization that in order to develop the baseline scientific knowledge to address societally relevant questions over societally relevant time frames, we need vastly improved data coverage, data interpretation approaches and techniques, and a workforce unlike anything that currently exists. Therefore, it is important to acknowledge and describe some of the successes that the U.S. has led, to help frame the discussion of immediate and future needs. I need to emphasize that the below four discussions are representative, and not an exhaustive listing.

Argo
The Argo Program is a global array of 3,800 free-drifting instruments, initially spaced about every 3° of latitude and longitude, including in the seasonal sea-ice zone and marginal seas. The floats move up and down in the water from the sea surface to 2,000 meters (about 1.2 miles, vertically) every 10 days and collect up to 1,000 measurements of temperature, salinity, and depth. Argo provides the first ever global-scale, all-weather, all-season subsurface observations of the oceans.

Before Argo, the temperature and salinity of the subsurface oceans could only be measured from ships or fixed-point moorings. As a result, these measurements were nowhere near as globally distributed as Argo provides. Since the first Argo float deployments in late 1999, over 1.6 million profiles have been collected which more than doubles the number from research vessels during all of the 20th century. Each year, Argo adds more than 120,000 new profiles. Argo is now the preeminent source of information about the climatic state of the oceans.

Pilot efforts to enhance the core Argo Program are in various stages of development. Some of these enhancements include floats sampling deeper than 2,000 meters (Deep Argo, below), carrying additional sensors to measure biogeochemical parameters (BGC Argo, below), and increased coverage in polar regions and in areas of the ocean with high variability (Polar Argo, below).

Today, Argo provides an unprecedented dataset that is freely available for researchers studying the temperature, salinity, and circulation of the global oceans and how these change over periods ranging from days to decades. These estimates allow the development of climate indicators such as the recent changes in ocean heat content and sea level. Argo data are also vital for climate and ocean forecasting services (from days to years), which are used for many applications such as search and rescue, crop management, and disaster preparedness.

Deep Argo: A new generation of autonomous floats called Deep Argo will sample the full ocean depth and volume. Deep Argo float models include the Deep SOLO and Deep APEX capable of reaching 6000 meters, and the Deep ARVOR and Deep NINJA designed to sample to 4000 meters. Regional Deep Argo arrays in the Southwest Pacific Basin, South Australian Basin, Australian Antarctic Basin, and North Atlantic Ocean are leading the way forward to implement a standing Deep Argo array of 1,228 floats. An exciting transition to systematic full-depth global ocean observations is happening.

Biogeochemical-Argo: (BGC-Argo) is the extension of the Argo array of profiling floats to include floats that are equipped with biogeochemical sensors for pH, oxygen, nitrate, chlorophyll, suspended particles, and downwelling irradiance. A BGC-Argo array would enable direct observation of the seasonal- to decadal-scale variability in biological productivity, the supply of essential plant nutrients from deep-waters to the sunlit surface layer, ocean acidification, hypoxia, and ocean uptake of carbon dioxide. It would extend ocean color remote sensing observations deep into the ocean interior and throughout the year in cloud covered areas. The system would drive a transformative shift in abilities to observe and predict the impact of climate change on ocean ecology, metabolism, carbon uptake, and marine resource modeling.

Polar Argo: Argo floats have been successfully deployed in the seasonal ice zone of both poles over the past decade. More than 45,000 profiles south of 60°S have been collected since 2001. Advances in float technology including two-way communications through the Iridium satellite network, software modifications (ice avoidance algorithm and the ability to store winter profiles) and improved hardware have resulted in ice floats surviving multiple winters under sea ice. In recognition of the successful deployment of floats into the seasonal ice zone and the desire for a truly global Argo data system, the Argo Steering Team has recommended that core Argo be extended beyond 60°S and 60°N.

In order to advance the Argo program nationally and globally, the community must find additional resources to ensure the sustainability of the existing array—which experienced funding reduction in the U.S. in 2019—and support for expansion into Deep, BCG, and the high latitudes floats.

Research Highlight: Reading the ocean's memory

A 2019 analysis by Geoffrey Gebbie (WHOI) and Peter Huybers (Harvard) of thousands of measurements from the HMS Challenger expedition, the scientific voyage that sailed around the globe from 1872 to 1876. Their work revealed that the deep Pacific Ocean is still feeling the effects of the Little Ice Age that chilled surface waters between the 16th and 19th centuries. Although the decrease in temperature is small, the volume over which it is occurring is extremely large and highlights the long climate memory of the ocean.

A lack of sustained observations from the deep ocean means the role that the region plays in the climate system has likely been underestimated. It also forced researchers to look to the historical record for insight. They found that the deep Pacific underwent a net cooling over the 20th century, despite warming almost everywhere else. Basic climate questions like the role of the deep ocean will remain unanswered with sufficient precision until more sustained observations of basic parameters like temperature are gathered and incorporated into state-of-the-art models to reduce predictive uncertainty.

Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP)
Despite numerous technological advances over the last several decades, ship-based hydrography remains the only method for obtaining high-quality, high spatial and vertical resolution measurements of a suite of physical, chemical, and biological parameters over the full water column. Ship-based hydrography is essential for documenting ocean changes throughout the water column, especially for the deep ocean below 2 kilometers (which represents 52 percent of global ocean volume not sampled by Argo and other profiling floats).

Global hydrographic surveys have been carried out approximately every decade since the 1970s through research programs such as GEOSECS, WOCE, JGOFS, and CLIVAR. However, global repeat hydrography has lacked formal global organization since the end of WOCE and this has led to a lack of visibility for hydrography in the global observing system as well as a significant decrease in the number of trans-basin sections carried out by some countries. More importantly, the lack of international agreements for implementation of hydrographic sections has led to disparate data sharing policies, duplication of some sections, and sections being carried out without the full suite of core variables.

The Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP) brings together scientists with interests in physical oceanography, the carbon cycle, marine biogeochemistry and ecosystems, and other users and collectors of ocean interior data, and coordinates a network of globally sustained hydrographic sections as part of the global ocean/climate observing system including physical oceanography, the carbon cycle, marine biogeochemistry and ecosystems.

GO-SHIP provides approximately decadal resolution of the changes in inventories of heat, freshwater, carbon, oxygen, nutrients and transient tracers, covering the ocean basins from coast to coast and full depth (top to bottom), with global measurements of the highest required accuracy to detect these changes. The GO-SHIP principal scientific objectives are: (1) understanding and documenting the large-scale ocean water property distributions, their changes, and drivers of those changes, and (2) addressing questions of how a future ocean will increase in dissolved inorganic carbon, become more acidified and more stratified, and experience changes in circulation and ventilation processes due to global warming and altered water cycle. The GO-SHIP program provides a vitally required baseline of data necessary for other programs, such as Argo, to use as a core global reference source. .

Long Term Ecological Research (LTER) Network

The Long Term Ecological Research (LTER) Network was founded in 1980 by the National Science Foundation with the recognition that committing to long-term research could help unravel the principles and processes of ecological science, which frequently involves long-lived species, legacy influences, and rare events. As policymakers and resource managers strive to incorporate reliable science in their decision making, the LTER Network works to generate and share useful and usable information.

Thus, LTER's mission is to provide the scientific community, policy makers, and society with the knowledge and predictive understanding necessary to conserve, protect, and manage the nation's ecosystems, their biodiversity, and the services they provide. Sites that support significant ocean-focused research include Beaufort Lagoons, California Current Ecosystem, Florida Coastal Everglades, Georgia Coastal Ecosystems, Moorea Coral Reef, Northeast Shelf, Palmer Antarctica, and Virginia Coast Reserve. Recent additions to the LTER coastal suite are the Northern Gulf of Alaska and the Northeast U.S. Shelf sites. The latter site leverages other National Science Foundation (NSF) investments in the Martha's Vineyard Coastal Observatory (MVCO) and the Ocean Observatories Initiative (described below).

Ocean Observatories Initiative (OOI)

The NSF-funded Ocean Observatories Initiative (OOI) is an integrated infrastructure program composed of science-driven platforms and sensor systems that measure physical, chemical, geological, and biological properties and processes from the seafloor to the air-sea interface. The OOI network, which is operated by WHOI, the University of Washington, Oregon State University, and Rutgers University, was designed to address critical science-driven questions that will lead to a better understanding and management of our oceans, enhancing our capabilities to address critical issues such as climate change, ecosystem variability, ocean acidification, and carbon cycling in key locations of the ocean and seafloor in the Northern Hemisphere.

The OOI has transformed research of the oceans by integrating multiple scales of globally distributed marine observations into one observing system and allowing for that data to be freely downloaded over the internet in near-real time. The OOI intends to deliver data and data products for a 25-year-plus time period within an expandable architecture that can meet emerging technical advances in ocean science. Building on last century's era of ship-based expeditions, recent technological leaps have brought us to the brink of a sweeping transformation in our approach to ocean research – the focus on expeditionary science is shifting to a permanent presence in the ocean. As technological advances continue over the lifetime of the OOI, developments in sensors, computational speed, communication bandwidth, internet resources, miniaturization, genomic analyses, high-definition imaging, robotics, and data assimilation, modeling, and visualization techniques will continue to open new possibilities for remote scientific inquiry and discovery.

Research Highlight: Engaging the fishing community

Waters off the southern New England coast teem with marine life and support an active commercial fishery. These waters have been historically fished since before the arrival by the Pilgrims, and served as the initial stimulus for Europeans to explore North America. But in recent years fishermen have noticed conditions in the region are changing to an extent and in a way not seen previously. In particular, they have seen rising water temperatures, changing currents, and the arrival of new species. This led Glen Gawarkiewicz (WHOI) to more formally incorporate their observations into his studies of the shelfbreak, where coastal and deep-ocean waters mix.

In 2014, he teamed up with the Commercial Fisheries Research Foundation (CFRF) to create the Shelf Research Fleet, which is made up of commercial fishing vessels that fish in or transit through waters off the Northeast Coast. The partnership between scientists and commercial fishermen has proven to be a cost-effective way to collect much-needed scientific data from a critical part of the ocean also occupied by elements of OOI and LTER. The project also has contributed significantly to a more holistic approach to science, in which different constituencies "coproduce" data and observations. Fishermen, for example, reported some of the first signs of a 2016-2017 marine heatwave that reached 6°C above average at its peak, when boats caught Gulf Stream flounder and juvenile black bass—warm-water fish not common in northern waters.

Relevance of SROCC findings for the U.S. Economy and National Security

The findings of the IPCC SROCC report findings have direct and significant relevance to the U.S., clearly demonstrating the impact of ocean and climate on our economic and national security, as well as on the health and productivity of marine ecosystems that provide much of our sustenance and societal well-being. Our collective capacity to understand, assess, adapt to and mitigate the impacts of the potentially profound changes that will accompany a rapidly warming climate will require much better operational modeling and forecasting of both large scale processes—heat, carbon, freshwater budgets—and those that influence our daily lives, including weekly, sub-seasonal, seasonal, and annual weather forecasts, fisheries stock assessments, marine biodiversity, and extreme weather events. There are also very real national security implications associated with having improved knowledge of the ocean environment as we face challenges from adversaries in the undersea domain.

Economic Security

The U.S. is a maritime nation, bounded by ocean on three coasts and the Great Lakes to the north. We have over 95,000 miles of coastline, and our Exclusive Economic Zone (EEZ) is 11,351,000 km^2 or 4,383,000 square miles, larger than the nation's continental land area. According to NOAA, coastal counties of the U.S. are home to over 126 million people, or 40 percent of the nation's total population, of which approximately 40 percent fall into an elevated coastal hazard risk category. The risk management company AIR Worldwide (https://www.air-worldwide.com) estimates that, based on maximum modeled storm surge extent, the total value of residential and business insurable property in ZIP codes on the East and Gulf Coasts potentially impacted by storm surge is $17 trillion. This large value is actually a minimum estimate, as it does not include public infrastructure such as roads, ports, railways, wastewater and drinking water facilities, and military bases, or uninsured property.

The changing climate also has implications for the commercial and recreational fishing industries, whose combined total sales in 2016 was $212 billion according to the National Marine Fisheries Service. And while more difficult to quantify, there are also potential impacts on the U.S. ocean-based tourism and recreation, which according to NOAA contributes approximately $124 billion in gross domestic product to the national economy each year. The 2018 National Climate Assessment further puts the total GDP from shore-adjacent counties at $7.2 billion, nearly half of the total U.S. GDP for 2013 (https://nca2018.globalchange.gov/chapter/8/). These indeed are large and significant contributors to the U.S. economy's overall well-being and long-term growth and viability.

Returning to the theme of my testimony, I will reiterate the importance of the ocean and coastal observing enterprise's role supporting efforts to improve our capacity to predict and refine knowledge of the timing, scale, and range of anticipate changes. Improved ocean and coastal observations and monitoring will continue to help shape and guide improvements in operational modeling and forecasting. These modeling improvements, including greater quantification and refinement of the value of natural resources, which will in turn drive advances in risk assessment and risk management capabilities. The improved risk data and modeling forecasts will greatly assist public and private sector decision makers, as well as citizens, make the necessary cost/benefit assessments and tradeoffs that will accompany personal, business, and public policy decisions that will have significant short- and long-term fiscal, social, environmental, and military implications. For example, insurance and re-insurance giants such as Swiss Re are deploying sophisticated business approaches to the problem given that the global re-insurance industry is managing total assets of about $30 trillion (roughly three times the size of China's economy (https://www.swissre.com/risk-knowledge/mitigating-climate-risk.html).

Research Highlight: Forecasting rainfall from sea-surface salinity

Sea-surface salinity is a natural indicator of precipitation and evaporation in the ocean, a key part of the global water cycle. Low salinity signals large inputs of freshwater from rainfall have occurred and high salinity indicates elevated evaporation transferring water from the ocean to the atmosphere. Over a career of studying the global water cycle, Ray Schmitt (WHOI) developed a method of forecasting precipitation in places like the U.S. Midwest and African Sahel based on sea-surface salinity patterns.

His work went largely unrecognized by traditional funding sources, so he turned to the Bureau of Reclamation's Sub-Seasonal Forecast Rodeo, in which teams worked to provide the best three-to-six-week precipitation forecasts over a year-long competition. Schmitt and his sons used sea-surface salinity data gathered by NASA, NOAA, and other sources, combined with artificial intelligence techniques, to outperform all other competitors—including professional forecasting companies and a climate model developed by NOAA. This work is an excellent example of how distant ocean processes affect weather even in the interior of continents, and speaks to how ocean observations of basic parameters such as salinity can deliver key information back for societal benefit

National Security and Defense

Finally, improved awareness of ocean processes through advances in ocean observations and modelling is critical to our national security in light of the renewed Great Powers Competition with China and Russia, particularly in the undersea domain. There are issues both within our EEZ as well as in far-flung ocean regions in which the benefits of ocean observing will be immediately felt. Military strategy is strongly influenced by situational awareness and those warfighters on the side with better knowledge of the seascape will be better positioned to take advantage of this information in times of peace as well as in the event of a conflict.

A nuance to some but of immediate practical importance to our national defense is the fact that because the ocean environment has changed significantly over the past few decades some of the historical ocean data is obsolete. There is an irony here. We have a strong understanding of the past conditions in key areas, which benefits our comparisons to the modern ocean and means we can identify where and what type of measurements are needed to better constrain uncertainty in our understanding of climate change. At the same time, these changes limit the operational capabilities of our systems of national defense.

For example, consider underwater acoustics—the process by which we monitor the presence of submarines and other underwater objects. Acoustical properties are strongly influenced by changes in water density, which is dictated primarily by heat and salinity as well as the presence of biology, such as plankton and fish. Any improvement in the collection of undersea data will help make the ocean more transparent to our military, allowing them to better monitor the position of the underwater assets of our competitors, as well as position our own assets where they are less likely to be observed. This is why the U.S. Navy has historically been at the forefront in the development and deployment of certain types of advanced underwater technologies, supported by the Office of Naval Research (ONR) and other defense entities. Partnerships between ONR and academia have yielded exceptional benefits in this arena over the past 80 years.

Recommendations

Sustaining Ocean Observations to Understand Future Changes in Earth's Climate
National Academies of Sciences Ocean Studies Board Workshop Report (2017)

As I noted earlier in the testimony, in 2017, the National Academies Ocean Studies Board convened members of the earth and ocean sciences community to consider processes for identifying priority ocean observations that will improve understanding of the Earth's climate processes and the challenges associated with sustaining these observations over long time frames, as well as approaches for overcoming these challenges. Their conclusions are very insightful, and, in addition to the following highlight of some of the most salient ones, I have provided a more thorough summary of the report's key findings as an appendix to this testimony.

First, it is helpful to summarize some basic ocean observation facts:

- Ocean observations are made using both satellite and in situ (in water) instrumentation.
- In situ observations are carried out using fixed and mobile platforms such as tide gauges, data buoys, moorings, ship-based observations, profiling floats, ocean gliders, and surface drifters. This is a representative list only.
- Priority ocean variables observed for climate are sea state, ocean surface stress, sea ice, sea surface height, sea surface temperature, subsurface temperature, surface currents, subsurface currents, sea surface salinity, subsurface salinity, ocean surface heat flux, and dissolved inorganic carbon.
- The ocean observing enterprise is an end-to-end system built on engineering, operations, data management, information products, and the associated human capabilities, which are supported by the planning and governance by international coordination entities and by regional and national agencies.

The Value of Sustained Observations

In the face of a changing climate, society will increasingly face complex decisions about how to adapt to and mitigate the adverse impacts of climate change such as droughts, sea-level rise, ocean acidification, species loss, changes to growing seasons, and stronger and possibly more frequent storms. To make informed decisions, policy makers will need information that depends on understanding the dynamics of the planet's climate system. Because these dynamics will evolve as the climate warms, the ability to anticipate and predict future climate change will depend on ongoing observations of key climate parameters to tune and enhance models. Sustained collection of ocean observations over years, decades, and centuries monitoring the Earth's main reservoirs of heat, carbon dioxide, and water will provide a critical record of long-term change and variability over multiple timescales. Sustained observations of environmental variables –including essential ocean variables—are thus essential to advance understanding of the state of the climate system now and in the future.

Highlights of Report Findings

Progress and Benefits

We need to start by recognizing the progress that has been made by the current ocean observing system and the benefits it has provided. Our increasing awareness of the major role the ocean plays in climate processes is due largely to ongoing observation programs supported by governments in the U.S. and abroad, which are focused on improving our understanding of the planet's heat, carbon and freshwater budgets, and the many subprocesses entrained within them. NOAA, NSF, NASA, and the U.S. Navy are the core supporters of ocean and coastal observing systems, but there are additional contributors across the federal agencies. This system contributes not only to our understanding of climate variability and change, but also to a wide variety of other services including weather and seasonal-to-interannual forecasting, living marine resource management, and marine navigation. As noted previously, this understanding of climate variability and change and other services underpins national defense, economic, and social policy decisions.

We must also recognize that the U.S. ocean observation enterprise is part of a broader collaborative and cooperative Global Ocean Observing System (GOOS). The GOOS effort is guided by the Framework for Ocean Observing, which helps identified priority observation, known as Essential Ocean Variables and requirements for their precision, frequency, spatial resolution. There are opportunities to increase the spatial coverage of observation through increased coordination and sharing of resources, as well as leveraging GOOS to enhance capacity building and support for observations in other nations.

Challenges

While the current U.S. ocean observing system is functional and has made considerable advances over the past 10 years, it is woefully undersized and is often inadequately funded to fulfill existing information demands, much less future demands. The workshop report identifies the absence of an overarching long-term (e.g., 10-year) national plan with associated resource commitments and lack of strong leadership as two key challenges for sustained U.S. ocean observing, which inhibit effective coordination and multiyear investments in the many components of the observing system.

These weaknesses are evidenced by recent challenges experienced across the observing system. This includes relatively flat funding for "Sustained Ocean Observations and Monitoring" program within NOAA Oceanic and Atmospheric Research (OAR). This program supports funds a range of in-situ global observing capabilities, including the Argo and Deep Argo programs, the Tropical Pacific Observing System, moored and drifting buoy arrays and global reference systems, gliders, and tide gauges. Collectively, these programs are critical to our nation's environmental observation system. The in situ ocean data these programs provide are essential to ground truthing satellite-based ocean observations. The program also provides critical ocean observations in the equatorial Pacific Ocean necessary to understand and forecast El Niño events, which have major economic and societal impacts in the U.S. and worldwide

Over the past decade, all elements of the NOAA program have experienced a substantial reduction in deliverables and/or degradation of services impacting operational activities and limiting scientific advances important to understanding and improving our weather and climate forecast systems. For example, in FY2019, Argo annual float deployments dropped well below its 350-unit target, to 273 units, which, if repeated in future years, will result in significantly reduced global coverage for the program.

Similar funding challenges are impacting the federal research fleet and its capacity to support ocean and coastal observations. The report finds that research vessels are indispensable to the ocean observing system and require long-term planning and investment. It states that maintenance of a capable fleet of research vessels is an essential component of the U.S. effort to sustain ocean observing. However, NOAA struggles to keep it only global class vessel operating in order to support its ocean observation missions. NSF's academic fleet is similarly fiscally challenged, particularly in supporting the cost of annual deployment and replacement of key global reference systems buoys, particularly in the southern polar latitudes, an area where there is limited understanding of what is believed to be the location of significant transfer of heat between the ocean and atmosphere.

In addition, the report finds the ocean observing program has been further impeded in its ability to adopt new advanced technologies, transition research observations to operations, and address new, high-priority observing opportunities. The limited investment in advancing technological capabilities is a challenge that, if addressed, will yield significant returns over the lifetime of sustained observing platforms through development of more robust, efficient and hopefully less costly sensors and platforms. The potential for autonomous underwater vehicles to collect large amounts of data is immense; however, the deployment of fleets of such vehicles requires major advances in software as well as underwater communications, for which funding is often difficult to secure. This situation is further impacted by challenges related to limited professional rewards or career incentives at research institutions and laboratories to ensure intergenerational succession of scientists, engineers, and technical staff, a reminder that workforce development is an often overlooked, but critical element of the systems long term success.

It is difficult to overstate the importance of establishing and sustaining databases of essential ocean variables. These databases allow scientists to observe changes over long periods of time and across wide areas or, as is more important in the ocean, over vast volumes. Doing so greatly improves our understanding of the underlying processes and the rate at which change is occurring in various systems. It also helps differentiate between natural variability, such and the Pacific and Atlantic decadal oscillations, and those influenced by human activities. When long-term observations are halted or broken, the discontinuity in the database can never be rectified –you cannot go back in time to collect data—and this compromises the reliability of models and forecasts based on this data. Years and decades in the future, scientists will rely on, and carefully scrutinize the quality of the data we collect today, so one of our core obligations is to identify the proper variables to observe and monitor, and maintain the integrity of these datasets for future use. Therefore, the report emphasizes the importance of planning end-to-end scope of expenses associated with observing programs, including appropriate logistical planning.

Finally, the report raising awareness of the importance and value of sustained ocean climate observations could increase support for the observing system from multiple sectors, including philanthropic organizations. This opportunity will be one area of focus of the second phase of the study that is scheduled to start later this month where new models or approaches to sustained ocean observing will be pursued. Additionally, the global ocean observing community convened for its decadal gathering last September in Hawaii (http://www.oceanobs19.net) and their recommendations for advancing the global system are expected to be refined and released later this year.

Research Highlight: Australia and the Indian Ocean

Australia is burning, but to understand how the relentless heat, blazing wildfires, and dry conditions on land have reached such extremes, Caroline Ummenhoffer (WHOI) and Gerald Meehl (National Center for Atmospheric Research) is looking to the ocean. Ummenhofer studies how ocean patterns in the Indian Ocean influence rainfall and extreme events—such as droughts and floods—on adjacent landmasses.

In particular, Ummenhoffer is looking to the Indian Ocean as a key driver of Australian rainfall variability. Her work has shown that unusual conditions occurred in the Indian Ocean during all major prolonged 20th century drought episodes in Australia. Among these drivers is a weather pattern called the Indian Ocean Dipole (IOD)—a phenomenon similar to the Pacific Ocean's El Niño—which can cause see-saw-like variations in sea surface temperatures across the eastern and western Indian ocean every 3-6 years on average. A record Indian Ocean dipole event occurred during the second half of 2019, during which stronger monsoon winds in the eastern Indian Ocean pushed warm waters to the western Indian Ocean. The warm water brought heavy rainfall and floods to Africa, while Australia and Indonesia experienced reduced cloud cover and moisture.

The Ocean Observation Enterprise

As I stated at the outset of this testimony, and as I hope is bolstered by the information presented here, *my singular recommendation relates to the need for a significantly enhanced ocean observation enterprise across ocean science disciplines, geographic regions, and temporal and spatial scales in the ocean*. The societal value of the data gathered by such ocean observations is ultimately related to its relevance to policy-makers in formats that clearly indicate the level of scientific confidence in its credibility and the clarity of any subsequent analysis and its ability to communicate trends and implications.

Climate impacts are appearing more rapidly and widely than anticipated, including in the ocean, which has increased the urgency for near real-time, ocean and coastal basin-wide observations (writ large, including associated infrastructure). Thus, this ocean observation enterprise must be done in partnership with private industry and public policymakers who are charged with making decisions that have long-term fiscal implications, and who are in need of improved certainty/confidence in climate information/data to facilitate risk assessment and risk management at the local, regional, national and international level. The limited availability of ocean data is a significant factor hampering our ability to improve the predictive capabilities of climate and weather models, which is key to helping identify solutions, and quantify risk, that can scale to meet the magnitude of the challenges associated with a rapidly changing climate.

Concluding Thoughts

As I hope has become clear from this testimony, there are many implications of the SROCC report and associated challenges and needs in the ocean science community. However, the one that stands out the most, and one that is being focused on across on virtually all scientific disciplines in the ocean science community, is the need for improved observations such as I discuss throughout this testimony. This includes data collection, processing, and synthesis to facilitate its incorporation into models and predictions improvement, as well as driving new research avenues per the findings and recommendations of NAS Sustaining Ocean Observation 2017 workshop report I highlighted earlier in my testimony.

I also recommend that you read the testimony provided by Alexander ("Andy") Karsner in September, 2019, before the House Financial Services Subcommittee on National Security, International Development ,and Monetary Policy. Karsner is a well-known American technology entrepreneur, venture capitalist, and energy and environmental policy-maker and he spoke very cogently about the relationship between better data on climate change and national economic opportunities (https://financialservices.house.gov/uploadedfiles/hhrg-116-ba10-wstate-karsnera-20190911.pdf). I have highlighted some of his key points below, as I see them, because they emphasize the importance of and opportunities associated with climate data to the economic welfare of the nation. The essence of his recommendations are captured in his statement regarding the need to quantitatively measure the environment in order to better incorporate its value into the management and stewardship process:

> *"To manage and integrate the value of natural capital, we know we must measure it – not qualitatively and theoretically, but quantitatively and precisely. We can only truly manage what we can measure.... If we can measure and manage, then we also have the potential to continuously monitor and ultimately monetize the value of nature's ecosystem services. This would enable the ultimate achievement: internalization of environmental externalities, and transparency for the systems that secure our health and well-being."*

Karsner's testimony is wide-ranging, addressing advances in artificial intelligence and machine learning in the financial sector, and notes that technological advances hold great promise not just for the future, but are ready now to be "widely deployed" through many sectors. It provides an interesting context to the springboard on which ocean science finds itself now, ready to vault into a future of innovative observations to modernize our understanding of the ocean.

Let me unequivocally state that there is a clear role for U.S. federal government investment in the collection of ocean and coastal data, one that private industry is very unlikely to every provide. Consider that the National Weather Service (NWS), which is a part of NOAA, plays the leading role in collecting and disseminating weather data, which is then used by private industry to develop value added products such as the plethora of weather apps on smartphones. The investment in the federal weather enterprise is huge, on the order of tens of billions of dollars, with the NWS annual budget used to operate and modernize the system. Although an excellent case of how government investment leads to private industry's success and to enhance public safety and quality of life, it is but one example of many. Unfortunately, given the importance of the ocean to climate and weather as described throughout my testimony, such investments in the ocean domain lag far behind their necessity.

While there is an existing ocean observing enterprise that includes ships, satellite sensors, buoys, drifters, floats, gliders, and autonomous underwater vehicles, technology development, high performance computers, and so on, it is a small fraction of the size of existing observing systems used for monitoring the land and atmosphere. For example, it is particularly problematic that the agency charged with supporting operational ocean observing systems—NOAA—has struggled for years to fund even the most basic programs and supporting infrastructure. The "Sustained Ocean, Coastal and Great Lakes Observations" budget line in NOAA OAR has essentially been level funded for the past 7 years (there is a $1 million increase provided in FY 2020 appropriations). This has resulted in NOAA decreasing its support for the critical and valuable ARGO program, reducing support for key surface mooring that are reference sites used to calibrate and validate satellite data., Furthermore, NOAA has struggled to keep their research fleet operating, which has further limited the deployment of ocean observing assets.

The overall state of affairs of NOAA is a reflection on the ocean science community's lack of success in communicating to Congress, the Administration(s), and more importantly the taxpayer, about the need for a robust, modernized, and sustained ocean and coastal observing system. It is my hope that the recent IPCC SROCC report will be the turning point where acknowledgement of the ocean's role in climate, and our economic and national security, will result in a commitment to forging an ocean observing enterprise that can fulfill the challenge of providing the data necessary to calibrate the rate of climate change, its impacts, and support decision making on adaptation and mitigation policies, in addition to ocean stewardship.

I close by noting that there are those who question whether we are losing the "race" between the speed of climate change and our ability to react. Regardless of how we are going to mitigate and/or adapt to the environmental changes we observe, Earth is still going to exist. Thus, the question is not really about a "race", but instead about how habitable will it be for our species. We live here, and it's the only planet I know that we can live on. Rather than winning or losing a race, we should look at whether we are peacefully coexisting with the environment, since it is the environment that is truly what sustains us. If we face an environment that is changing more rapidly than we anticipated, it does not mean we will lose the race, it means we will have to take more extreme actions to adapt.

It's easy to get discouraged, but that's where the science we do has a huge objective role to play. We are collecting unimpeachable data from our ocean, documenting the changes, comparing those to documented changes from the past, and then using that knowledge to inform our predictions for the future. With your continuing support for ocean science and observations, we can help meet future challenges with the best available information.

I thank you for the opportunity to appear before the Committee.

Dr. Richard Murray
Deputy Director and Vice President for Research
Woods Hole Oceanographic Institution

Rick Murray is the Deputy Director and Vice President for Research at the Woods Hole Oceanographic Institution. He was a Professor of Earth and Environment at Boston University (BU) from 1992 - 2019. He served as Director, Division of Ocean Sciences at the National Science Foundation (NSF) from 2015-2018. In addition to his NSF duties, he served as a Co-chair for the Subcommittee on Ocean Science and Technology, as part of the Office of Science and Technology Policy in the Executive Office of the President, during both the Obama and Trump administrations. While at BU, Murray was the Director of the BU Marine Program from 2006-2009, and Chair of the Department of Earth Sciences from 2000-2005. He received his undergraduate degree at Hamilton College (1985), and also graduated from the Sea Education Association's (SEA's) program in Woods Hole (Class W-71). After receiving his Ph.D. from the University of California at Berkeley (1991), he was a post-doctoral scholar at the Graduate School of Oceanography, University of Rhode Island.

Murray's research interests are in marine geochemistry, with an emphasis on sedimentary chemical records of climate change, volcanism, and tropical oceanographic processes, and in the chemistry of the subseafloor biosphere. A seagoing oceanographer, he has participated on many research cruises in various capacities around the globe. He has authored or co-authored nearly 100 peer-reviewed research papers, is a Fellow of the Geological Society of America, a former Trustee of SEA, and helped initiate and manage the Link Foundation's Ph.D. Fellowship Program in "Ocean Engineering and Instrumentation". Murray is a former Councilor of The Oceanography Society, and is currently on the Board of Directors of the American Geophysical Union. He was an elected Selectmen in Scituate, MA, from 2006 to 2014, and has been active in town governance for many years.

Chairwoman JOHNSON. Thank you very much. Dr. Steltzer.

TESTIMONY OF DR. HEIDI STELTZER, PROFESSOR OF ENVIRONMENT AND SUSTAINABILITY, FORT LEWIS COLLEGE, COLORADO

Dr. STELTZER. Chairwoman Johnson, Ranking Member Lucas, and Members of the House Committee on Science, Space, and Technology, I'm grateful for the invitation to be here with you all today.

I'm a scientist and explorer and a science communicator. I prefer to go where the temperatures are cool, the snow is deep, the plants are small, and the opportunity for collaborative science to understand our planet is huge. I have conducted field studies in remote mountain and polar regions for 25 years in Colorado, Alaska, Greenland, and most recently on the Tibetan Plateau in China. I'm a Professor at Fort Lewis College, which is in Durango, Colorado, in the Four Corners region.

The United States is not the most vulnerable nation to climate change, though we have already been and will continue to be impacted. It is difficult to comprehend what the costs of further inaction could be. Many of the cryospheric changes described in the most recent IPCC report, the one that Dr. Murray also spoke of, and further summarized in the Cryosphere 1.5° C report that I provided as part of my testimony, may seem far away in time or in space. The cryosphere is the frozen water on our planet. It's the regions across the Earth where there is snow, permafrost—permanently frozen ground—and ice.

In these regions, what are we seeing? We're seeing rapid ice sheet deterioration in Antarctica; fall and perhaps sooner winter without Arctic sea ice; increasingly more unfrozen ground across Russia, northern Europe, and North America, including Alaska; disappearing mountain glaciers in Peru; and mountains with less snow.

Due to the volume of ice and the greater permanence when ice is lost, the changes to snow may be overlooked by the media and policymakers, but these changes in snow are not overlooked by the farmers, the ranchers, the water managers, the skiers, and the business owners in the community where I live.

In my community on the western slope of Colorado, we talk about snow a lot. We talk about climate change, we talk about less snow, we talk about wildfire, and we talk about all those things amidst also talking about powder days, recent adventures, and how our children are doing. We don't often talk in rural western Colorado about Arctic sea ice or ice sheets in Antarctica, though these, too, will affect us.

What are some of the ways the cryosphere is changing that should be discussed more across all of America? Changes to ice are irreversible on time scales that are relevant for policy. Abrupt processes occur. We know of some of these but not all, and by their nature we don't know when they'll occur. And in the world's mountains, not just in the U.S. mountains, the presence and persistence of snow is changing. There is less snow.

In every community across the United States temperature extremes are affected by cryospheric changes that influence air circulation. Melting ice affects the rate of sea-level rise in coastal regions. The loss of ice and thaw of permafrost affect the acceleration of warming and melting and the chance to keep our planet below 1.5° C warming over pre-industrial times. More extreme temperatures, less reliable water, and the pace of these changes affect food energy and water supply. There is much we can do.

So what can we do? Our country should aim to be a resilient nation. Resilience is coping capacity. It's coping capacity in response to unknown shocks, trends, or stresses. Resilience includes the capacity to adapt and to transform to reduce the impact of climate change or other environmental changes. Individuals, communities, and nations can be resilient, and our Nation should aim to be a resilient nation.

What motivated me to pursue a career in science may be similar to what motivates many of you to be Members of Congress: The opportunity to do some good for others. We can work to achieve this together.

Three of my recommendations parallel ones many people in the international world have heard recently. Some of our steps forward can be to protect the lands that have not yet been transformed by our actions. The value of land that we have not yet changed is immense. We can restore lands that have been transformed so that they store more carbon, hold onto more soil, and reduce the impact of extreme weather events. We can fund both of these efforts. Federal funding for lands protection and restoration form the foundation for communities to be resilient.

The one other piece that I'd like to add that I think parallels some of what was shared by Mr. Lucas is that we can develop a new narrative about climate change, and where and how we tell stories is a really important part of climate change. We often focus a lot on what is lost, what is irreversible, and what is harmful, and I felt I needed to speak to that, but we can also focus on what we can do differently. Snow, plants, and soil are renewable resources. We can work to build capacity for the lands to be more vibrant and more healthy and more green and for there to be more snowfall once again across the U.S.

Thank you.

[The prepared statement of Dr. Steltzer follows:]

On Frozen Water: Why the Cryosphere Matters for Each of Us

Statement of

Heidi Steltzer
Professor of Environment and Sustainability, and Biology,
Fort Lewis College, Durango, Colorado

before the
Committee on Science, Space, and Technology
U.S. House of Representatives

for the hearing
An Update on the Climate Crisis: From Science to Solutions

15 January 2020

Chairwoman Johnson, Ranking Member Lucas, and members of the House Committee on Science, Space, and Technology, I greatly appreciate the invitation to join you here today for a conversation about the climate crisis, the cryosphere, and actions that will lead to the future we all want. I speak today as a mountain and Arctic scientist, an explorer and educator, and as a private citizen who lives in the rural, western United States on the ancestral lands of the Ute, Apache, the Pueblos, Hopi, Zuni, and the Diné Nation.

My approach to communicate climate science is often through narrative with myself a character in the story. Skillful narratives about the changes taking place on our planet due to the high emissions of carbon dioxide from burning fossil fuels are essential to bridge divides, communicate science to diverse audiences, and develop and implement resilience planning. Our actions have led to the Climate Crisis. The commitment of U.S. Congress to action this month and each month this decade is essential to reduce risk and grow resilience to the many environmental threats our country currently faces. Growing our resilience to one environmental threat increases resilience to them all.

The narrative that is part of this written testimony is about my journey in mountain and Arctic science. It's inspiration and basis is from the places I have conducted research, lived in the mountains, and the many people with whom I've spoken about environmental changes to learn about their concerns. To complement the narrative, my testimony begins with a list of key points, summarizing ideas in the narrative, and adding key points that I could not weave into the story and some must-note key points on the climate crisis. I have also chosen to submit as a part of my testimony the *Cryosphere1.5°: Why Cryosphere Dynamics Demand 1.5° Pathways for 2020 and Beyond* report http://iccinet.org/cryosphere15/ led by the International Cryosphere Climate Initiative and released in December 2019. I and many other scientists across different areas of cryosphere expertise contributed to this policy-focused document.

My perspective on key points about the climate crisis, cryosphere science and solutions:

1. Growing our resilience to one environmental threat, such as climate change, increases our resilience to them all. Our goal is resilience and for this we need to protect our planet's frozen water by limiting warming over preindustrial times below 1.5°C.
    a. Resilience planning and implementation are essential. There is tremendous cost-savings and life-savings if we focus our efforts on preventing disasters rather than 'putting out fires'.
    b. One cannot assume that what is important to them is important to others. Thus, when we see a pattern of change over time, we should ask people if it is important to them that for example there are fewer fish or there is less ice. We can explore together what might explain the observed changes and the implications of these changes for the future. Scientists can choose to expand our approaches for science, which would benefit from government support.
2. The Climate Crisis is real and I am concerned about the future. I am concerned that Americans will be harmed much more greatly than they already have been harmed, that livelihoods will be lost, and unprotected public lands that are being developed won't provide critical benefits to people, including carbon storage, soil stabilization, disaster regulation and water supply, in the future.
    a. Land and ocean protection are essential to American resilience at local, regional, national and global scales. Conservation is fundamental to resilience and should be a government funded, national priority.
    b. The wisdom and cultures of Native Americans, Native Alaskans, and Native Hawaiians and Pacific Islanders is essential to grow our resilience as a nation. I am grateful for the lessons I've learned by listening to their narratives. As a nation and in our communities, we can build inclusive spaces that value their perspectives and include them more in decision-making.
    c. People and countries with fewer economic resources will experience greater harm, though they've contributed less to the crisis. Federal actions to limit climate injustice are essential.
3. The world is 70% ocean and very blue. The world is also green and brown and white. The white surfaces of Earth, where the frozen water of the cryosphere is most evident, provide balance for sustaining air flows, the location of climate zones, and the rate of heating on our planet. With less white, a region and the Earth as a whole warms faster.
    a. Ice sheets, sea ice, and glacier ice are being lost at extraordinary rates in nearly every region of the Earth. Loss perpetuates further loss for many reasons. Loss will continue for decades, centuries and millennia even if carbon dioxide emissions from fossil fuels were zeroed out today. For this reason, resilience planning and implementation are critical. The rate of change must slow to allow people to adapt, changing what we do in small and big ways.
    b. When ice is lost, we are losing an ancient resource, one created under greatly different climate conditions. Ice cannot rapidly be restored.
    c. Snow is different than ice, because for many regions of the Earth, including those in the United States, snow falls, accumulates and melts on an annual cycle. The snow supplies our rivers and thereby people across our continent with water, even where snow rarely falls, such as Oklahoma, Texas and Arizona. The paths and

economic value of water from snow in rivers across the United States are well mapped. Snow is a national asset.

d. Snow also recharges groundwater reserves that are critical to sustain water supply to rivers, agriculture, industry and citizens in times of low precipitation and low river flows. Our understanding of the sensitivity of groundwater recharge to climate change is poor and improving this understanding is critical to growing resilience.
e. The presence and persistence of snow is changing in the world's high mountains, including in the western United States. Ecosystems are impacted. Many plants are growing less and others are dying, though the death of plants due to less snow is not clear. We don't yet know the consequences of changes in plant cover, biomass, species abundances, and the timing of their growth on water supply, carbon storage or nutrient and metals retention in mountain watersheds.
f. Many of the changes to ecosystems and their benefits for human well-being may be due to changes in ice and snow that have not yet been demonstrated through quantitative observations and analyses published in peer-reviewed science journals. The lived-experiences of indigenous and local people living in mountain regions and adjacent deserts are essential to fill this knowledge gap and inform resilience planning.
g. Permafrost is different from ice and snow; it is the frozen, carbon-rich ground that releases carbon dioxide and methane to the atmosphere as it thaws. This is a destabilizing process that accelerates the heating of our planet and proceeds over time in leaps of abrupt change. We are leaping forward with exceedingly high and uncontrolled carbon emissions from the Earth's frozen ground. The only way to slow this process is to keep the Earth below 1.5°C relative to preindustrial times.

4. Reducing any, and all, other stresses on plants and restoring lands will grow resilience and sustain the benefits of ecosystems, including the diversity and beauty of our mountains. Due to warming temperatures and declining snow, our 'purple mountain majesties' are at risk of long-term changes, some of which would be irreversible.
    a. Due to topography, nooks and crannies as well as great heights, mountains protect biodiversity and people when climate changes. Mountains offer protection from heat and store water. Mountains are a national asset. Migration paths for diverse species and people require protection and international agreements to allow migration out of unsafe climate zones to the south or in lowlands to safe ones.
    b. The western United States may be the only mountainous region for which there are published studies in peer-reviewed scientific journals that demonstrate the link between changing snowpack and wildfires through earlier snowmelt. The link is more evident in Arctic regions. Actions that protect snow reduce the risk of wildfire and its impact on water availability, water quality and air quality. Protecting deserts protects snow by retaining soil in desert lands.
5. The air and water connect us all. To grow our resilience, people need to be connected across air and watersheds. It is essential that we talk about change and what we will do to grow resilience.
    a. I recommend that U.S Congress create a U.S. Corps of Social, Environmental and Engineering Sciences (SEES). The SEES Corps would form an extensive network of centers across the country. Centers would be spaces to gather, exchange

knowledge, build trust and implement innovations for monitoring, restoring and protecting ecosystem benefits for human well-being. These centers would grow our resilience to all environmental threats.

b. The UN Intergovernmental Panel on Climate Change (IPCC) has developed a robust process to assess the causes and consequences of climate change based on published studies in peer-reviewed scientific journals. The SEES Corps could develop a process to synthesize what we know through other knowledge systems, those of people who have long-lived on and directly manage the nation's lands and waters. People could be paid for their investments in knowledge exchange, and their tribes or organizations be provided with funds for resources, such as stream gauges and sensor networks, to ensure reliable water, energy and food.
c. Internationally, U.S. leadership on climate change is irreplaceable. The absence of U.S. leadership at the recent COP in Madrid had a negative impact. If you are from a state that is part of the U.S. Climate Alliance, I encourage that you support the work of your state, including their planning for nationally determined contributions (NDCs) to take to COP26.
d. The climate crisis and increasing loss of our cryosphere can be a tipping point towards compassionate leadership and resilience mindedness in the United States. For many, there are barriers to participate in science and resilience planning. These barriers need to be removed, so that more people of color, more indigenous people, more women, more people from rural regions, and more immigrants have the opportunities that I and others have had. This will lead to new ways of conceptualizing and solving the climate crisis.

A journey in mountain and Arctic science to inform solutions for the climate crisis:

In the summer of 2000, when I was 28 years old, I was on a bush plane bound for a remote river valley in the Brooks Range, Alaska. I'd recently finished my PhD in December at the University of Colorado, Boulder. I'd camped out in a bouncy castle for Y2K, because I didn't think the electric grid would fail. And, I'd said no to working at a prestigious research institution. They offered the opportunity to be part of National Science Foundation (NSF) funded research at the foremost Arctic field station in the United States. I would have slept in a bed, studied the tundra outside my dorm, eaten meals that I did not have to prepare, and measured the nitrogen and carbon in Arctic plants and soils.

Instead, I chose to step off a bush plane onto a gravel bar, cross a braided river, and walk up a headwater stream of the Noatak River on frozen water. I chose to sleep in a Mountain Hardware tent, eat canned chili and pilot bread, and measure the nitrogen and carbon in Arctic plants and soils. The field work I did was similar, but the learning was far greater.

Why? I immersed myself. I stepped away from books and computers. I walked the land, sinking into frost boils with each step. It was easy to tell where the permafrost began. It was the depth to which my foot sunk in August, when all the ground that would thaw that season had thawed.

There weren't many fish in the river on which I was camped that summer. Over pizza or standing on Front Street looking out across the Chukchi Sea, people in town would ask me if I knew why and offer their ideas. It was common to exchange ideas about how something that was important, such as fish or ice, was different than in the past, what might explain the change, and contemplate what this might mean for the future. If we do not talk honestly about change and prepare for it, we risk food security, reliable water, safe transit, and safety during catastrophic events. We risk human lives and the loss of essential species. We must find ways past the politics and reinvest in conversation about our changing planet.

As our planet warms, and it is warming, ice is melting, permafrost is thawing, lakes are being lost while others are forming, snowlines are moving up in latitude and elevation, and polar rivers and seas have less ice. Is this important? What do you think might explain this? What might it mean for the future?

This is what brings us together today. Every tenth of a degree matters by influencing the amount of water that falls as rain instead of snow and the amount of ice that melts. If the Earth is less white, which it is, it warms up faster, air flow patterns change, winter and summer precipitation patterns shift, and seas rise. As permafrost warms, it thaws and could add two atmosphere-equivalents of carbon dioxide to our skies. Abrupt thaw process in permafrost-rich lands are a sudden, destabilizing process in the Earth's climate system.

Frozen water is vital for human well-being.
The cryosphere matters for each of us.
The cryosphere must be protected.

The experience of living in a rural Arctic region, in a community with many Inuit, and public radio as it was meant to be led to my choice to live in Colorado's San Juan Mountains, teach at a Native American Serving Non-Tribal Institution, and make sure that the lands I study most often are ones I know well. It's not just through my research that I learn about the land, but also through conversations with people across Colorado where I've lived since I was 22 years old. There once were country doctors who made house calls and knew their patients well. I'm a country scientist with a tough diagnosis to share, one that is informed by my investment in work with the IPCC, conversations with many, and my own research and observations.

For 24 years I studied mountains and Arctic lands before being asked in 2018 to contribute as a lead author for the chapter on High Mountain Areas for the recently released IPCC Special Report on the Oceans and Cryosphere in a Changing Climate (SROCC). I said yes. Then, I searched for articles in scientific journals, I read them, searched some more, and read some more. It's incredible how many papers one needs to read to find the ones that are relevant to the scope of an IPCC report. I mention this and want to assure you, that as authors, we are not biasing which articles we pick to include based on our views. Authors aren't part of the scoping for the report – the IPCC and governments do this part of the process. Authors are tasked to find articles relevant to the agreed on scope. We consider and include the evidence from all of the articles within the scope, especially the few that show a different pattern from many others.

Here's how this works. In the high mountains of Colorado, where I do my field work to characterize how plants are responding to changing snow dynamics and what this means for water supply to the Western United States, plants are growing less. The changes in snow lead to insufficient water for at least some part of the summer. Many of the plants, but not all, are adapted to this. Some die. If they are trees and there are many, we read about it in the news, because their trunks and branches remain visible evidence of what was lost. Some plants may die without a trace, unless there are baseline data to know they were there. Many plants just grow less.

Through my review of published scientific articles for the IPCC report, I learned that these same patterns were reported in many other mountain regions, but not in all. On the Qinghai-Tibetan Plateau in China and near Mount Everest in Nepal, it is warming and plants are growing more. Is this important? Why might this be? What does it mean for the future? Scientists in China and Nepal are working to answer these questions, just as we are doing here in the United States. We often lack baseline data. We don't have all the answers and this too is valuable to explain.

In middle school, high school and college, students that excel in science courses are often doing well because they invest time to study and retain information well. Science appears true or false. Science appears 'cookbook'. But it's not. Science is not a cookbook or a short story. It's a saga.

Here's one way that science works. Each year, at winter's end, the researchers with whom I work and I wait for snow to melt. We also melt snow early to have study plots that vary only in one factor from the others, the controls. We measure everything that is possible with the equipment that we have. Sometimes, we have what we most need, a $50,000 field spectrometer to measure light reflectance of plant canopies across 10 nm bands of light for visible, near infrared, and shortwave infrared regions of the energy spectrum.

Sometimes, we don't have the equipment we need, and we just use our eyes to count plants, measure plant height or identify which species have green leaves on a weekly basis. I've done this for many years across different mountain and Arctic regions. Other research teams have observed flowering times, which affect species survival, in the same places for over forty years.

The expensive part of science isn't the equipment. It's our salaries and health care. It's the logistical costs to go to remote mountain and polar regions and sustain field stations, basecamps, and their staff in places where cryospheric changes are impacting climate regulation for our planet. I'm grateful the NSF Office of Polar Programs has a budget for logistics. Growing logistics budgets across programs in environmental sciences and creating more opportunities for field stations and basecamps to receive funds directly for the infrastructure and support they provide scientists would be beneficial. Increasing and sustaining logistics funding for field studies is critical.

Once collected, our data reveal patterns, stories about how plants respond to changing snow. Often it's been different than I expected in Alaska tundra, in alpine basins and across elevation from mountain valleys to their peaks. This leads us to collect more data across different snow years and sites. I recently travelled to China to plan for a snow experiment there and presented a vision for a global network of snow experiments across mountain and polar regions at the American Geophysical Union's annual meeting in December. There is no clear way to fund this international effort on the needed time scale of a few years. Many scientists face this challenge.

Sustained funding of science should match the magnitude and scale of the climate crisis and support diverse approaches to science.

Scientists develop and use new approaches to measure the same things we did before. We integrate our data into models. We develop predictions from the models and use them to plan for new field studies. We retest our initial idea, the model predictions, and the conclusions of our initial results. If we don't scrutinize our ideas, data, models, and conclusions, other scientists will. Published journal articles that underlie IPCC reports are the routine communication of research as chapters, while the saga goes on for decades and involves many.

We, scientists, government and citizens, have been on a journey together to uncover what is changing on our planet due to our actions. We've learned a lot over the past few decades, and we know the Earth is changing in ways we did and did not expect. To limit our risks, we have just one decade to agree it's important, affirm together it is us, and accept responsibility that our actions must change.

If you or if many of the constituents in your district, question the data or scientists' conclusions about the causes and consequences of climate change, I encourage you to see for yourself and share what you learn with them. Yes, this is an open invitation for a personal tour of a mountain watershed in Colorado, a tundra walk in Alaska, or a glacier trek in Greenland. These are places I know well, and we can invite others with indigenous knowledge who know them better than I to join us. If you'd like to see the Arctic sea ice or Antarctic ice sheets, I have friends who could help with this.

If you choose Colorado, you might think to come in winter when there is skiing, or in summer for the wildflowers or to escape uncomfortably high summer temperatures where you live. But the seasons to come to understand our changing mountains best are when snow first accumulates, especially if snow arrives late, or during melt season, better known as mud season in the mountains. This is the time of year when the mountains are waking. Water is rushing across the land and to great depths where it recharges groundwater. Much of the water that falls as snow sustains rivers and us indirectly by moving first to groundwater, then in time to mighty rivers, when they are at their lowest flows. In this way, much of the water in my state makes its way to your states, in ways that science can demonstrate well and in ways we still need to figure out.

The saying is that 'seeing is believing' and some of the evidence is in our backyards as well. In my backyard, I've seen double rainbows, red moons, meteor showers and bear. In my backyard, there are dense scrub oak, a plant that I know can carry fire quickly from the valley below to the hilltop on which I live. In 2018, there were helicopters and planes flying across my backyard. They flew for over a month through smoke-filled skies, most often in the evening while we were eating dinner on our deck. They carried fire retardant and reservoir-filled tubs of water. That fire was 10 miles from my home. For many people I know, that fire was in their backyard.

The fires currently burning across Australia feel close to me, because I have many friends in Australia. I have friends who have left their homes to stay safe, are wearing face masks to stay safe, and are putting out and tracking the fires to keep others safe. As I worked on the IPCC SROCC report, the western United States was the only mountainous region for which I could find published scientific articles that link less snow to increased risk of wildfire. The link has greater confidence for Arctic regions. The lesson of Australia is that it is dangerous and costly to become the poster child for climate change. The United States is providing support to fight the fires in Australia. We should also learn from their mistakes. Their government spent about $2.7 billion per year on recovery from disasters between 2010 and 2013, and only $100 million per year on resilience. A disaster risk reduction framework that the government developed lacked the needed 2019 implementation plan. We can all do better.

In times of crisis, which I consider this to be, governments invest funding, companies invest funding, private foundations invest funding, and people invest time. Firefighting, evacuation, disaster relief and disaster recovery funds are raised to manage in times of crisis. As a country, we may have far more systems in place to make significant and immediate decisions about raising and spending large sums of money as and after loss and damage occur rather than to prevent them. We also have a culture that, as it should, has tremendous respect for firefighters and rescue workers who volunteer their time and risk their lives. Scientists who do research and communicate their insights hoping to avert disaster are often mistrusted, though some risk their lives and many risk their reputation. I'm grateful for their efforts. They are heroic in under recognized ways.

To accept the science and solve the climate crisis, it's important to know scientists and in knowing us, trust the work in which we've invested ourselves. I and many other scientists would like the chance to cultivate trust. If a diagnosis from a doctor is limited life expectancy, we often chose to see another doctor and possibly another. The diagnosis doesn't seem real unless it is a doctor we trust. A*n extensive network of Social, Environmental and Engineering Sciences Centers across the country could advance inclusion and ensure there are scientists with indigenous, local and professional knowledge everywhere.*

I was shocked by the ice on an Arctic river in summer when I began to do field research in the Brooks Range, Alaska. I'd known still water could freeze. I had not realized flowing water could freeze and form ice over a meter thick. Standing on the ice and seeing its cross section made it real. Solid river and sea ice ensure safety for people who must travel across frozen rivers and seas for food, commerce and to visit family in regions where they have lived for thousands of years. Ice and snow provide water and climate stability for human well-being across the Earth. The time is now to build bridges of trust that connect citizens, governments and science.

Dr. Heidi Steltzer

Dr. Heidi Steltzer is a Professor of Environment and Sustainability and Biology at Fort Lewis College in the San Juan Mountains, Colorado. Dr. Steltzer is a co-Principal Investigator on the U.S. Department of Energy's Watershed Function Scientific Focus Area that is led out of the U.S. DOE Berkeley Laboratory, California, with field studies based at the Rocky Mountain Biological Laboratory in Gothic, Colorado. She is on the board of directors for the Center for Snow and Avalanche Studies in Silverton, Colorado, and the Western Alliance for Restoration Management at Western Colorado University, Gunnison, Colorado.

Dr. Steltzer is a lead author for the chapter on High Mountain Areas in the 2019 Intergovernmental Panel on Climate Change (IPCC) Special Report on the Oceans and Cryosphere in a Changing Climate. She is also a science editor on the 2019 Cryosphere 1.5C Report produced by the International Climate Cryosphere Initiative. She is a member of the American Geophysical Union (AGU), and an advocate in AGU's Voices for Science program launched in 2018 to promote communication about the value and impact of Earth and space science to decision makers, journalists, and public audiences. She was a participant in the inaugural year of Homeward Bound, an Australian-based leadership program for women in science, which aims to increase the influence of women in science in solving environmental issues.

Dr. Steltzer is a mountain and Arctic scientist, explorer, and science communicator. She studies how environmental changes affect mountain watersheds and Arctic ecosystems and their link to our well-being. She has spent 25 years conducting field studies on mountain and Arctic hillslopes in Colorado, Alaska, Greenland and recently China. She's pioneered studies on the impacts of earlier snowmelt through experimentally accelerating snowmelt and monitoring plant and ecosystem responses. Her field studies lead to an experiential approach to higher education, in which she creates opportunities for student-led inquiry into environmental issues. Fort Lewis College, where she has been a professor since 2009, is a Native American Serving Non-Tribal Institution in the American Southwest. Her experiences engaging with students have influenced her choice to invest in science communication and climate diplomacy. Dr. Steltzer earned her BS in Biology at Duke University. Her doctorate is in Ecosystem Ecology from University of Colorado at Boulder. Find her on social media @heidimountains.

Chairwoman JOHNSON. Thank you very much. Mr. Shellenberger.

TESTIMONY OF MR. MICHAEL SHELLENBERGER, FOUNDER AND PRESIDENT, ENVIRONMENTAL PROGRESS

Mr. SHELLENBERGER. Good morning, Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee. I'm very honored to be here. I'm an energy analyst and environmentalist dedicated to the goals of universal prosperity, peace, and environmental protection. Between 2003 and 2009 I advocated for large Federal investments in renewables, many of which were made as part of the 2009 stimulus. And since 2013 I've worked with climate scientists for the continued operation of nuclear plants around the world and have helped prevent emissions from increasing the equivalent of adding 23 million cars to the road.

I also care about getting the facts and the science right. I believe scientists, journalists, and advocates have an obligation to represent climate science accurately even if doing so reduces the saliency of our issue. No credible scientific body has claimed climate change threatens the collapse of civilization, much less the extinction of the human species, and yet some activists, scientists, and journalists have made such apocalyptic assertions, which I believe contribute to rising levels of anxiety, including among adolescents and worsening political polarization.

My colleagues and I have carefully reviewed the science, interviewed the scientists and other individuals who have been making these claims, and written a series of articles debunking them. In response, the Intergovernmental Panel on Climate Change has invited me to review its next assessment report, and HarperCollins will publish our research findings as a book this June.

While climate change may make some natural disasters more frequent and extreme, the death toll from extreme events could and should continue to decline, as it did over the last century by over 90 percent, even as the global population quadrupled. Does that mean we shouldn't worry about climate change? Of course not. Policymakers routinely take action on non-apocalyptic problems, and the risk of crossing unknown tipping points rises with higher temperatures.

But we should recognize that humans are not passive victims of environmental change. The Netherlands grew very rich while farming up to 7 meters below sea level. Poor nations like Bangladesh can and should manage a gradual sea-level rise of 2 feet over the next 80 years. In fact, they're working with the Dutch on that very project right now.

Future food production will depend far more on whether poor farmers gain access to tractors, irrigation, and fertilizer than temperature rise according to the best available science assembled by the Food and Agriculture Organization, which calculates crop yields, will continue to rise even in high-warming scenarios.

And there's much we can do to reduce the impacts of climate-driven extremes. For example, the most important factors behind rising severity and frequency of fires in California and Australia are the buildup of wood fuel in forests and the expansion of homes and other buildings in fire-prone areas, both of which can be addressed to protect human lives and those of endangered species.

While the world appears to be headed to temperature rise closer to 3° centigrade over pre-industrial temperatures rather than 4, thanks largely to abundant natural gas, nothing is guaranteed. As such, the American people have an interest in supporting reasonable measures to transition from carbon-intensive to low-carbon fuels in order to prevent global temperatures from increasing by more than 3 degrees.

The most important of these measures by far is the expanded use of nuclear energy. Thanks in part to decades of public and private investment in fracking, natural gas is today cheap and abundant and thus needs little in terms of new public policy. Solar and wind are popular but their inherent unreliability, large land-use requirements, and large materials requirements mean they make electricity expensive, have large environmental impacts, and are inherently limited in their capacity to replace fossil fuels.

Consumers in States with renewable energy standards spent $125 billion more for electricity than they would have otherwise over the last decade according to University of Chicago economists in a research report last year. Germany spent €32 billion annually on renewables, which is the equivalent of the U.S. spending $200 billion annually between 2014 and 2018, only to increase its share of electricity from solar and wind by 11 percentage points. French electricity, which 72 percent nuclear, produces 1/10 of the carbon emissions as renewables-heavy German electricity at nearly half the price.

The U.S. invented nuclear energy for civilian use in the 1950s, and yet over 3/4 of new nuclear reactors globally are being built by the Chinese and Russians. Everyone recognizes that for the U.S. to compete in building nuclear plants abroad, we must build them at home, and yet electric utilities may close half of America's nuclear plants over the next 2 decades.

While the nuclear industry deserves great credit for the continuous improvement of power plant safety and efficiency, many utility executives today are either resigned to the technology's decline or engaged in wishful thinking. Even were utilities to replace every nuclear plant it closes with small modular reactors, the electricity generated would be roughly 2/3 less. And if nations were to one day opt for smaller reactors, they would likely purchase them from those nations that offer the most favorable financial terms and have the most experience, which is Russia and China.

Given all of that, I would like to post three questions as a public-interest advocate of the environment and of nuclear. First, is it in the interest of taxpayers to subsidize U.S. electric utilities to operate existing nuclear plants in the absence of any commitment to build new nuclear plants? Second, does Congress believe the U.S. can compete with China and Russia while shutting down half to 2/3 of its nuclear fleet? Third, is Congress really comfortable standing by and watching dozens of nations partner with China and Russia to expand their use of nuclear over the next century?

If the answer to the latter question is yes, I think Congress should inform the American people that it has decided to cede America's historic role as creator, promoter, and steward of the world's most sensitive dual-use technology to our main geopolitical rivals.

In the 1950s, Members of Congress understood the sensitive and special nature of this technology and pressured a distracted White House to make American dominance of nuclear energy a top national security priority. I think that the same thing is required today. We need a new act of Congress, perhaps a revision to the *Atomic Energy Act*, and perhaps we should call it a Green Nuclear Deal in recognition of its importance not just to national security but also to the economy, the environment, and the climate. Thank you very much.

[The prepared statement of Mr. Shellenberger follows:]

Testimony of Michael D. Shellenberger, President, Environmental Progress, to the House Committee On Science, Space, and Technology, An Update on the Science of Climate Change, January 15, 2020

Good morning Chairman Johnson, Ranking Member Lucas and members of the committee.

My name is Michael Shellenberger, and I am Founder and President of Environmental Progress, an independent non-profit research organization funded by charitable philanthropies and individuals with no financial interest in our findings.[1] As background, I am an invited expert reviewer of the next assessment report by the Intergovernmental Panel on Climate Change (IPCC), a regular contributor to the *New York Times, Washington Post, Forbes*, and other publications, and a *Time Magazine* "Hero of the Environment."[2]

I am honored to address the Committee on the state of climate science and opportunities to mitigate and adapt to climate change from the perspective of someone who has worked at the intersection of climate science, energy, and policy, for 20 years.

I. State of Climate Science

Climate change is an issue I care passionately about and have dedicated a significant portion of my life to addressing. In 2003 I co-founded the Apollo Alliance to advocate for a Green New Deal, which we called a "New Apollo Project." Many of this proposal's ideas for renewables, efficiency, and electric vehicles were funded under the 2009 America Recovery and Reinvestment Act. Since 2016, my organization, Environmental Progress, has worked with the world's leading climate scientists to persuade lawmakers to keep nuclear plants operating in Illinois, New York, Connecticut, New Jersey, and Ohio, and preventing emissions from increasing the equivalent of adding 24 million cars to the road.

I also care about getting the facts and science right. Some scientists, journalists, and policymakers, have in recent months made a number of apocalyptic predictions about the impact of climate change, including that sea-level rise will be unmanageable, that farmers will not be able to grow enough

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[1] Environmental Progress publicly discloses its donors on its web site: http://environmentalprogress.org/mission.

[2] Michael Shellenberger, "Founder and President," Environmental Progress, 2020, accessed December 8, 2020, http://environmentalprogress.org/founder-president.

food to support half the human population, and civilization will end unless radical action is taken immediately.[3] The IPCC and other leading scientific assessments do not support these claims and yet some journalists, policymakers, and even some lead IPCC authors have repeated them.

Such claims may be contributing to rising levels of anxiety among adolescents. The American Psychological Association (APA) and the Climate Psychology Alliance (CMA) of the United Kingdom recently warned that a growing number of children are suffering from eco-anxiety.[4] Seventy percent of American teenagers call anxiety and depression a major problem, which is significantly more than who name bullying, drug addiction, or gangs as major problems.[5]

Over the last year, I have interviewed many of the individuals making apocalyptic claims, re-reviewed the science with the staff and scientific advisors of Environmental Progress, and written a series of articles for *Forbes* on inaccurate and unscientific claims being made with regard to climate change, fires in the Amazon, Australia, and California, sea level rise, and species extinction.[6]

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[3] Robinson Meyer, "The Oceans We Know Won't Survive Climate Change," *Atlantic*, September 25, 2019, https://www.theatlantic.com/science/archive/2019/09/ipcc-sea-level-rise-report/598765/; Gaia Vince, "The Heat is On Over the Climate Crisis. Only Radical Measures Will Work," *The Guardian*, May 18, 2019, https://www.theguardian.com/environment/2019/may/18/climate-crisis-heat-is-on-global-heating-four-degrees-2100-change-way-we-live; Andrew Freedman, "Climate scientists refute 12-year deadline to curb global warming,"*Axios*, January 22, 2019, https://www.axios.com/climate-change-scientists-comment-ocasio-cortez-12-year-deadline-c4ba1f99-bc76-42ac-8b93-e4eaa926938d.html.

[4] Sonia Elks, "Children suffering eco-anxiety over climate change," Reuters, September 19, 2019, https://www.reuters.com/article/us-britain-climate-children/children-suffering-eco-anxiety-over-climate-change-say-psychologists-idUSKBN1W42CF; Susan Clayton et al., "Mental Health and Our Changing Climate," American Psychological Association, March 2017, 27, 36, https://www.apa.org/news/press/releases/2017/03/mental-health-climate.pdf.

[5] J.M. Twenge et al., "Age, period, and cohort trends in mood disorder indicators and suicide-related outcomes in a nationally representative dataset, 2005-2017," *Journal of Abnormal Psychology* 128, no. 3 (March 14, 2019): 185-199, https://doi.org/10.1037/abn0000410; Juliana Menasce Horowitz and Nikki Graf, "Most U.S. Teens See Anxiety and Depression as a Major Problem Among Their Peers," Pew Research Center, February 20, 2019, accessed January 10, 2020, https://www.pewsocialtrends.org/2019/02/20/most-u-s-teens-see-anxiety-and-depression-as-a-major-problem-among-their-peers/.

[6] Michael Shellenberger, "Why Everything They Say About The Amazon, Including That It's The 'Lungs Of The World,' Is Wrong," *Forbes*, August 26, 2019. Michael Shellenberger, "Why Everything They Say About California Fires — Including That Climate Matters Most — Is Wrong," *Forbes*, November 4, 2019, https://www.forbes.com/sites/michaelshellenberger/2019/08/26/why-everything-they-say-about-the-amazon-including-that-its-the-lungs-of-the-world-is-wrong/; Michael Shellenberger, "Why Apocalyptic Claims About Climate Change Are Wrong," *Forbes*,

No credible scientific body has ever claimed climate change threatens the collapse of civilization much less the extinction of the human species.

While it is sometimes possible to discern the influence of climate change on natural disasters, that influence is often overshadowed by improved resilience, including by poor nations. The decadal death toll from natural disasters declined 92 percent from its peak in the 1920s. In that decade, 5.4 million people died from natural disasters. In the 2010s, just 0.4 million did.[7] Moreover, that decline occurred over a period when the global population nearly quadrupled.[8]

A major study in the journal *Global Environmental Change* last year found that the rates of death and economic damage had dropped by 80 to 90 percent over the last four decades.[9] The IPCC concludes that "Long-term trends in economic disaster losses adjusted for wealth and population increases have not been attributed to climate change, but a role for climate change has not been excluded."[10]

Sea levels rose 7.5 inches (0.19 meters) between 1901 and 2010 and IPCC estimates sea levels will rise as much as 2.2 feet (0.66 meters) by 2100 in its medium scenario. In the IPCC's high-end scenario, sea level rise tops out at 2.7

November 25, 2019, https://www.forbes.com/sites/michaelshellenberger/2019/11/25/why-everything-they-say-about-climate-change-is-wrong/. Michael Shellenberger, "Why Climate Alarmism Hurts Us All," *Forbes*, December 4, 2019, https://www.forbes.com/sites/michaelshellenberger/2019/12/04/why-climate-alarmism-hurts-us-all/.

[7] I am using decadal averages to avoid the risk of cherry-picking outlier years.

5.4 million people died from natural disasters. Hannah Ritchie and Max Roser, "Global deaths from natural disasters," Our World in Data, accessed October 25, 2019, https://ourworldindata.org/natural-disasters. Data published by EMDAT (2019): OFDA/CRED International Disaster Database, Université catholique de Louvain – Brussels – Belgium. Data for individual years summed over ten year intervals from the first to last year of each calendar decade.

[8] Global population in 2018: "Population Dynamics," United Nations Department of Economic and Social Affairs, 2019, accessed January 10, 2020, https://www.un.org/development/desa/en/key-issues/population.html; Estimate of global population in 1930: "The World at Six Billion," United Nations Department of Economic and Social Affairs, 1999.

[9] Giuseppe Formetta et al., "Empirical evidence of declining global vulnerability to climate-related hazards," *Global Environmental Change* 57 (May 25, 2019): 1-9. https://doi.org/10.1016/j.gloenvcha.2019.05.004.

[10] C.B. Field et al., *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, Intergovernmental Panel on Climate Change, Cambridge and New York: Cambridge University Press, 2012, accessed January 10, 2020, https://www.ipcc.ch/site/assets/uploads/2018/03/SREX_Full_Report-1.pdf; Laurens M. Bouwer, "Observed and Projected Impacts from Extreme Weather Events: Implications for Loss and Damage,"in *Loss and Damage from Climate Change*, eds. Reinhard Mechler et al. (Cham, Switzerland: Springer, 2019): 63-82.

feet (0.83 meters) by 2100.[11] Will societies will be able to adapt to such sea level rise? If they behave like the Netherlands then the answer is yes. It became one of the world's wealthiest nations while adapting to having one-third of its land mass below sea level, including some of its land laying seven meters below sea level.[12] And today, our capability for modifying environments is far greater than ever before. Experts from the Netherlands are already working with the government of Bangladesh to prepare for rising sea levels.[13]

In 2017 a large team of scientists modeled 37 different regions across the U.S. and found that "humans may not only influence fire regimes but their presence can actually override, or swamp out, the effects of climate."[14] Of the 10 variables that influence fire, they wrote, "none were as significant... as the anthropogenic variables," such as building homes near, and managing fires and wood fuel growth within forests.[15]

The same may be true for what we have seen in Australia. "Bushfire losses can be explained by the increasing exposure of dwellings to fire-prone bushlands," wrote a leading scientist in 2013. "No other influences need be invoked. So even if climate change had played some small role in modulating recent bushfires, and we cannot rule this out, any such effects on risk to property are clearly swamped by the changes in exposure."[16]

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[11] J.A. Church et al.,"Sea Level Change." In: *Climate Change 2013: The Physical Science Basis,* eds. T.F. Stocker et al. (Cambridge and New York: Cambridge University Press, 2013).

[12] The Zuidplaspolder in the western Netherlands is 6.76m below sea level. The IPCC in its Medium scenario (RCP4.5) predicts 0.39m median sea level rise in 2191-2200.

[13] "Bangladesh Delta Plan 2100," Dutch Water Sector, May 20, 2019, accessed January 10, 2020, https://www.dutchwatersector.com/news/bangladesh-delta-plan-2100; "Deltaplan Bangladesh," Deltares, accessed January 10, 2020, https://www.deltares.nl/en/projects/deltaplan-bangladesh-2/.

[14] Alexandra D. Syphard et al., "Human presence diminishes the importance of climate in driving fire activity across the United States," *Proceedings of the National Academy of Sciences* 114, no. 52 December 2017: 13750-13755, accessed November 2019, https://doi.org/10.1073/pnas.1713885114.

[15] Alexandra D. Syphard et al., "Human presence diminishes the importance of climate in driving fire activity across the United States," *Proceedings of the National Academy of Sciences* 114, no. 52 December 2017: 13750-13755, accessed November 2019, https://doi.org/10.1073/pnas.1713885114.

[16] John McAneney, "Climate change and bushfires - you're missing the point!," *The Conversation,* October 31, 2013, https://theconversation.com/climate-change-and-bushfires-youre-missing-the-point-19649.

Humans today produce enough food for 10 billion people, a 25 percent surplus.[17] When it comes to food production, the Food and Agriculture Organization of the United Nations (FAO) anticipates crop yields will continue increasing even in high-warming scenarios. FAO projects farmers in sub-Saharan Africa could see crop yields increase 80 to 90 percent. Future food production will depend more on whether farmers get access to tractors, irrigation, and fertilizer than on climate change, just as it has done for the last century.[18]

In late November 2019, a group of scientists argued in an opinion comment at the journal *Nature* that "evidence is mounting" that the loss of the Amazon rainforest and West Antarctic ice sheet "could be more likely than was thought."[19] However, IPCC does not predict the ice sheets would slide off quickly and instead, if they melt off, would do at a rate of one meter a century for several centuries.[20]

Humans are not on the precipice of a tipping point with regards to the melting of tundra in ways that would result in the rapid release of methane gas, concludes IPCC.[21] While the Atlantic Meridional Overturning Circulation (AMOC) it is indeed weakening, the IPCC says, "There is only limited evidence linking the current anomalously weak state of AMOC to anthropogenic [human-caused] warming," and that it has high confidence that is "very unlikely it will shut down before 2100."[22]

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[17] "The future of food and agriculture – Alternative pathways to 2050," (Rome: Food and Agriculture Organization of the United Nations, 2018): 82.

[18] "The future of food and agriculture – Alternative pathways to 2050," (Rome: Food and Agriculture Organization of the United Nations, 2018): 76-77.

[19] Timothy M. Lenton et al., "Climate tipping points — too risky to bet against," *Nature,* November 27, 2019, https://www.nature.com/articles/d41586-019-03595-0.

[20] Ove Hoegh-Guldberg et al., "Impacts of 1.5ºC Global Warming on Natural and Human Systems,"In *Global Warming of 1.5°C*, eds. Masson-Delmotte et al., (Intergovernmental Panel on Climate Change, 2019), https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter3_Low_Res.pdf.

[21] Ove Hoegh-Guldberg et al., "Impacts of 1.5ºC Global Warming on Natural and Human Systems,"In *Global Warming of 1.5°C*, eds. Masson-Delmotte et al., (Intergovernmental Panel on Climate Change, 2019), 262, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter3_Low_Res.pdf.

[22] Ove Hoegh-Guldberg et al., "Impacts of 1.5ºC Global Warming on Natural and Human Systems,"In *Global Warming of 1.5°C*, eds. Masson-Delmotte et al., (Intergovernmental Panel on Climate Change, 2019), https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter3_Low_Res.pdf.

If the Greenland ice sheet were to completely disintegrate, sea levels would rise by seven meters, but over a 1,000-year period. And for that to happen, temperatures would have to rise far more than anyone imagines.[23]

As for the Amazon, the IPCC says "the likelihood of a climate-driven forest dieback by 2100 is lower than previously thought."[24] IPCC has medium confidence that climate change alone will not drive large-scale Amazon forest loss by 2100 "although shifts to drier forest types are predicted in the eastern Amazon."[25]

Does any of that mean we should not care about climate change? Of course not. *Most* of the action that policymakers take is to address problems that are not apocalyptic. It is a peculiar feature of climate policy that its advocates feel the need to exaggerate with so much severity and frequency.

Since I published my articles, some people have asked me if some amount of exaggeration isn't required to address climate change. I give a very strong "no."

First, it is a profound privilege and responsibility to be in a position to represent complex scientific questions to mass audiences and policymakers. Anyone in that position must strive to represent the science with a strong commitment to accuracy, even if that accuracy reduces the salience and urgency of the problem one believes should be addressed. For a journalist, scientist, or activist to knowingly exaggerate a problem is unethical.

Second, past apocalyptic claims resulted neither in a binding international treaty nor an economy-wide cap and trade system. In 1989 "a senior U.N. environmental official" told Associated Press "entire nations could be wiped off the face of the Earth," "coastal flooding and crop failures would create an exodus of "eco- refugees,' threatening political chaos" and "governments have a 10-year window of opportunity to solve the greenhouse effect before it goes beyond human control."[26]

The good news is that the world appears to be headed to temperatures closer to two degrees than four, and there is a strong public interest to take reasonable measures to prevent temperatures from rising too high, just as there

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[23]Even if temperatures rose 6° Celsius, the Greenland ice sheet would lose just 10 percent of its volume over 400 to 500 years. Ove Hoegh-Guldberg et al., "Impacts of 1.5ºC Global Warming on Natural and Human Systems,"*Global Warming of 1.5°C*, eds. Masson-Delmotte et al., https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter3_Low_Res.pdf.

[24]*AR5 Climate Change 2014 – Impacts, Adaptation and Vulnerability*, Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press, 2014), 309.

[25]*AR5 Climate Change 2014 – Impacts, Adaptation and Vulnerability*, Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press, 2014), 309.

[26] Peter James Spielmann, "U.N. Predicts Disaster if Global Warming Not Checked," *Associated Press*, June 29, 1989, https://apnews.com/bd45c372caf118ec99964ea547880cd0.

is one for helping nations to develop and become more resilient to all extreme events. A new report by the International Energy Agency (IEA) forecasts carbon emissions in 2040 to be lower than in almost all of the IPCC scenarios.[27]

Part of the reason for lower anticipated future emissions and warming is due to the far greater abundance, and lower prices, of natural gas, which produces half the carbon emissions of coal. The shale fracking revolution occurred over a decade ago and breakthroughs in deepwater drilling occurred before that, and yet many scientists, journalists, and activists report on projections of future warming based on a world where coal is used up to five times more than it will likely be used.

IPCC needs to improve how it conducts and communicates scenario planning to provide policymakers and journalists with a more accurate picture of likely future warming than it has in the past. In the past, IPCC has summarized the science in its Summary for Policymakers, and the news media has summarized the Summary, in ways that seem designed to grab the public's attention.

Because there are strong incentives for some scientists, journalists, activists, and policymakers to exaggerate the science, it is incumbent upon other scientists, journalists, activists, and policymakers to point them out.

Happily that is starting to happen. Stanford University atmospheric scientist Ken Caldeira, who has raised the alarm about ocean acidification, stresses that "while many species are threatened with extinction, climate change does not threaten human extinction."[28] MIT climate scientist Kerry Emmanual has expressed a similar point: "I don't have much patience for the apocalypse criers. I don't think it's helpful to describe it as an apocalypse."[29] Another esteemed climate scientist I interviewed, Tom Wigley, who created one of the main models for predicting future temperatures, told me: "All these young people have been misinformed. It really does bother me because it's wrong."[30]

Said Emmanuel, "You've got to come up with some kind of middle ground where you do reasonable things to mitigate the risk and try at the same time to lift people out of poverty and make them more resilient."

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[27] "World Energy Outlook 2019," (Paris: International Energy Agency, 2019), https://www.iea.org/reports/world-energy-outlook-2019.

[28] Liz Kalaugher, "Climate scientist or climate activist — where's the line?" *Physics World*, September 2019, https://physicsworld.com/a/climate-scientist-or-climate-activist-wheres-the-line/.

[29] Dr. Kerry Emanuel (climate scientist, MIT) in discussion with the author, November 2019.

[30] These interviews became the basis for one of my columns. See: Michael Shellenberger, "Why Apocalyptic Claims About Climate Change Are Wrong," *Forbes*, November 25, 2019, https://www.forbes.com/sites/michaelshellenberger/2019/11/25/why-everything-they-say-about-climate-change-is-wrong/#7b14f08d12d6.

Happily, there is plenty of middle ground between climate apocalypse and climate denial.

II. Adaptation and Mitigation

Adaptation has been, and will likely remain, humankind's central response to changing climates for thousands of years. The fact that there are 7.5 billion humans, that most of us have escaped extreme poverty, and that rates of death and damage from natural disasters have declined 90 percent in a century, even in developing nations, is a testament to our species' extraordinary success.

Because the influence of climate change is largely overshadowed by economic development in developed and developing nations alike, it is a mistake for the United Nations developed nations to attempt to limit and direct foreign aid to address climate change specifically rather than resilience to extreme weather and economic development more broadly.[31]

I would urge you and your colleagues not to earmark development aid in such a way since doing so risks misdirecting financial aid to where it is needed most, and results in "false precision."[32]

As for decarbonization, I do not believe human societies will ever transition from fossil fuels to renewables because of their inherent unreliability, large land use requirements, and large materials requirements. A typical large solar farm in sunny California requires 380 times more land than the state's last nuclear plant to produce the same amount of energy, due to the low energy-density of sunlight and the high energy density of uranium.[33]

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[31] This framework has the additional disadvantage of leading representatives of some developing nations to exaggerate the role of climate change in disasters as a way to gain development aid from developed nations, which are disproportionately responsible for historic emissions and warming. For a personal account of how this happens, see: Richard Tol, "Why I resigned from the IPCCD WGII," Richard Tol, April 25, 2014, http://richardtol.blogspot.nl/2014/04/ipcc-again.html.

[32] Scientists who in 2018 had claimed that Hurricane Florence would produce 50 percent more rainfall and be 80 kilometers larger due to "human induced climate change" last week acknowledged that their "our forecasted attribution statements fall outside broad confidence intervals of our hindcasted statements and are quite different from the hindcasted best estimates." K. A. Reed et al., "Forecasted attribution of the human influence on Hurricane Florence," *Science* 6, no. 1 (January 1, 2020): https://doi.org/10.1126/sciadv.aaw9253.

[33] Diablo Canyon's facilities cover about 0.74 square kilometers, while the plant produced 18.3 terawatt-hours of electricity in 2018. Topaz Solar Farm covers 20 square kilometers, while the plant produced 1.3 terawatt-hours in 2018.

For those reasons, solar and wind farms make electricity more expensive everywhere they are deployed at scale.

Renewables contributed to electricity prices rising 50 percent in Germany since 2007, the first year it got more than 10% of its power from subsidized wind, solar, and biomass. By 2019, German household electricity prices were 45 percent higher than the European average.[34]

Renewables contributed to electricity prices rising seven times more in California than in the rest of the US since 2011, the state's "take-off" year for rapid growth in wind and solar, a price rise that occurred despite the state's reliance during the same years on persistently-low-priced natural gas.[35]

"All in all," wrote economists from the University of Chicago last year, "consumers in the 29 states [with renewable mandates] had paid $125.2 billion more for electricity than they would have in the absence of the policy."[36]

Neighboring France and Germany are illustrative. Nuclear-heavy French electricity produces one-tenth the carbon emissions as renewables-heavy German electricity at nearly half the price.

Despite investing nearly a half-trillion dollars, Germany still generates just 42 percent of its electricity from non-hydro renewables, as compared to the 72 percent France generates from nuclear.

Germany spent 32 billion euros on renewables every year between 2014 and 2018, or about one percent of its GDP a year, which would be like the United States spending $200 billion dollars annually, but only increased its share of electricity from solar and wind by 11 percentage points.[37]

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[34] Fridolin Pflugmann et al., "Energy Transition Index," Mckinsey & Company, November 2019, accessed January 10, 2020, https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/germanys-energy-transition-at-a-crossroads#.

[35] Eurostat, "**Electricity prices for household consumers - bi-annual data (from 2007 onwards)**" December 1, 2019, accessed January 20, 2020, https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_204&lang=en; "Electricity Data Browser: Retail Sales of Electricity Annual." United States Energy Information Administration, accessed January 10, 2020, https://www.eia.gov/electricity/data/browser/.

[36] Michael Greenstone and Ishan Nath, "Do Renewable Portfolio Standards Deliver?" Energy Policy Institute at the University of Chicago 62 (May 2019): 1-45, https://epic.uchicago.edu/wp-content/uploads/2019/07/Do-Renewable-Portfolio-Standards-Deliver.pdf.

[37] Frank Dohmen, "German Failure on the road to a renewable future," *Spiegel,* May 13, 2019, https://www.spiegel.de/international/germany/german-failure-on-the-road-to-a-renewable-future-a-1266586.html; Conversions made using OECD data for Purchasing Power Parity. "Annual Electricity Generation in Germany," Fraunhofer ISE, January 10, 2020, accessed January 10, 2020, https://www.energy-charts.de/energy.htm.

And the eight percent of Germany's electricity produced from burning biomass and energy crops is typically counted as renewable. If Germany didn't count emissions-producing and land-intensive fuels like these as renewable, which most environmental groups, including Greenpeace, believes it shouldn't, the share of its electricity from non-emitting, non-hydro renewables is just 34 percent.[38]

Nuclear plants are cost-competitive with both coal and natural gas in almost every part of the world. The United States is the major exception. The main reason nuclear is more expensive than it should be is its rigid and disruptive over-regulation, due to unfounded public fears. Nuclear is not only the safest way to make electricity, it has actually saved two million lives, according to the best available research.[39]

Only nuclear can substitute for fossil fuels while maintaining and increasing levels of energy consumption required for universal human prosperity. As such, one of the most important things policymakers can do for climate mitigation is to support the continued operation of existing, and building of nuclear plants.

Fears of nuclear power plants appear to be a form of psychological displacement, or scapegoating, stemming from fears of nuclear weapons. Anti-nuclear activists since the 1960s have implied that a nuclear accident would have

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[38] Fridolin Pflugmann et al.,"Energy Transition Index." *Mckinsey & Company,* November 2019, https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/germanys-energy-transition-at-a-crossroads; "BP Statistical Review of World Energy," British Petroleum, June 2019, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf.

[39] A selection of the literature on public health benefits of nuclear energy, and the consequences of its closure: Anil Markandya and Paul Wilkinson, "Electricity Generation and Health," *Lancet* 370, no. 9591 (September 2007): 979-990, https://doi.org/10.1016/S0140-6736(07)61253-7; Anthony J. McMichael, Rosalie E. Woodruff, and Simon Hales, "Climate change and human health: present and future risks,"*Lancet* 367, no. 9513 (March 2006): 859-869, https://doi.org/10.1016/S0140-6736(06)68079-3; "Ambient Air Pollution: a global assessment of exposure and burden of disease," World Health Organization, 2016, https://apps.who.int/iris/handle/10665/250141; "Nuclear Waste State-of-the-Art Report 2016: Risks, uncertainties and future challenges," *Swedish National Council for Nuclear Waste,* 2016, https://www.government.se/49bbd2/contentassets/ecdecd2ee26c498c95aaea073d6bc095/sou-2016_16_eng_webb.pdf; Pushker Kharecha and James E. Hansen, "Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power,"*Environmental Science and Technology* 47, no. 9 (March 2013): 4889–4895, https://doi.org/10.1021/es3051197; Edson R. Severnini, "Impacts of nuclear plant shutdown on coal-fired power generation and infant health in the Tennessee Valley in the 1980s,"*Nature Energy* **2** (April 2017), doi:10.1038/nenergy.2017.51

the same impact as a nuclear weapon,[40] a myth repeated by the 2019 HBO mini-series, "Chernobyl."[41]

Happily, fears of nuclear have proven to be unfounded. For a nation to get nuclear energy, it must submit to an extremely rigorous and invasive inspection regime. If there is a causal relationship between nuclear energy and weapons, it is in the opposite direction of what many believe. North Korea wanted nuclear energy, couldn't get it, but got nuclear weapons. South Korea has nuclear energy and no nuclear weapons.

Because of its inherently dual military-civilian nature, Congress and most presidential administrations have long viewed America's nuclear power plants, and our involvement in the nuclear energy programs of other nations, as top national security priorities. And yet today, the US nuclear industry is in a state of managed decline.

The U.S. has prematurely shut down six gigawatts of nuclear capacity since 2013 and another eight gigawatts are set to close over the next seven years. If this decline continues, China will surpass the U.S. in installed nuclear capacity by 2030 and by 2034 Russia may as well. These two nations are set to build over three-quarters of all new nuclear globally by 2025.[42]

As of early 2020, over 50 percent of nuclear power under construction today is in Russia or China, or is a project being built by Russia and China in third countries. And more than 80 percent of near-term nuclear projects likely to be in operation by 2030 are Chinese and Russian large light-water nuclear reactors. Argentina, Bangladesh, Belarus, Belgium, Bolivia, Brazil, Bulgaria, the Czech Republic, Egypt, Finland, France, Ghana, Hungary, India, Jordan, Kazakhstan, Kenya, Mexico, Nigeria, Poland, Saudi Arabia, Slovakia, South Africa, Sudan, Turkey, U.A.E., U.K., Ukraine, Uzbekistan, Zambia, and other nations are today seeking nuclear energy to meet their needs.

Are Congress and the White House really ready to stand by and let the above nations become tightly bound to China and Russia's through the world's most important dual-use technology? If so, then such a decision should at least be debated and formalized as it represents a significant break from U.S. national

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[40] Spencer Weart, *The Rise of Nuclear Fear* (Camrbidge: *Harvard University Press*, 2012).

[41] I covered this inaccuracy along with others in: Michael Shellenberger, "Why HBO's Chernobyl Got Nuclear So Wrong," *Forbes*, June 6, 2019, https://www.forbes.com/sites/michaelshellenberger/2019/06/06/why-hbos-chernobyl-gets-nuclear-so-wrong/.

[42] Mark Nelson and Madison Czerwinski, "GlobalOverview," Environmental Progress, 2020, accessed January 10, 2020, http://environmentalprogress.org/global-overview.

security policy for the last 75 years. If not, then it is incumbent upon both branches of the U.S. government to significantly increase American competitiveness in new nuclear plant building abroad.

For America to be competitive in selling nuclear plants abroad, we must be competitive in building nuclear plants at home. That's because nations seeking to build new nuclear power plants want to hire firms with significant construction expertise. And yet the opposite is happening now in the U.S.

The good news is that nations trust the United States more than China and Russia when it comes to nuclear energy, and with good reason. The US operates the most nuclear plants in the world and has the largest industry to draw upon. Our independent Nuclear Regulatory Commission is still considered the gold standard when it comes to safety regulation. And adopting American nuclear means benefitting from the US's unsurpassed safety record and excellent operational record.

Historically, Congress has been a crucial champion of nuclear energy. In the 1950s and 1960s, Congress pressured subsequent presidential administrations to make civilian nuclear energy a greater priority. I hope Congress will play a leadership role once again.

I am attaching an open letter to President Trump from leading energy, environmental, security and other experts and advocates, urging him and Congress to work together to protect and expand America's fleet of nuclear power plants.

Thank you again for the opportunity to testify. I look forward to your questions.

January 15, 2020

President Donald J. Trump

The White House
1600 Pennsylvania Ave NW
Washington, DC 20500

Dear President Trump,

We are writing as nuclear energy advocates and industry leaders to express our support for your goal of American energy dominance, offer our ideas and support for achieving that goal, and request a meeting to discuss them.

Every American president has made nuclear energy a high priority for national security, economic, and environmental reasons. In 1953, President Dwight D. Eisenhower gave his famous "atoms for peace" speech at the United Nations. There, Eisenhower pledged that the US would help nations use nuclear for energy, research, agriculture, and medicine to lift themselves out of poverty.

Atoms for Peace was remarkably effective. Since 1945, nuclear energy has been used solely for peaceful purposes. Nuclear has proven to be an affordable and reliable electricity source for the United States and other nations, including developing, vulnerable, and energy-poor ones. Nuclear has proven to be safe and clean. And today there is a strong consensus that nuclear must play a central role in any effort to reduce pollution including carbon emissions.

The US has for 60 years been the global leader in the development and building of nuclear plants around the world. Nine out of every ten gigawatts of global nuclear capacity today is descended from designs invented and commercialized by America. American nuclear reactor designs today operate in leading nuclear countries like China, France, South Korea, Japan, and the U.K. American reactors operated in the U.S. are the best in the world, operating 93 percent of the time.

Today, however, the US is building just one nuclear plant at home and none abroad, which is allowing China and Russia to dominate the market for nuclear. Nations seeking nuclear energy today who will be in need of a nuclear supplier include Argentina, Bangladesh, Belarus, Bolivia, Brazil, Bulgaria, the Czech Republic, Egypt, Finland, Ghana, Hungary, India, Jordan, Kazakhstan, Kenya, Mexico, Nigeria, Pakistan, Poland, Saudi Arabia, Slovakia, South Africa, Sudan, Turkey, U.A.E., U.K., Uzbekistan, and Zambia, among others.

Several of these countries are already getting reactors from China or Russia but have expressed a desire to explore all options for subsequent plants. Others are looking for reliable and friendly long-term partners for first plant projects, which can cost $10 to $20 billion dollars each and produce decades-long working relationships.

That is why nuclear is good business and could result in significant, durable revenue for American workers and industry. Russia currently has a nuclear plant order book valued at $134 billion, with about $100 billion of this outside of Russia itself. China's order book is similar, and although largely based on domestic projects, is poised to expand rapidly after it completes its first full-size exported plant next year in Pakistan.

The likely retirement of one-third to two-thirds of all US nuclear reactors over the next two decades exacerbates the threat to American nuclear leadership. Some US nuclear plants that could operate safely and reliably for another 40 years or more are at risk of being closed within in the next five years due to market distortions created by state and federal policies.

If the US nuclear energy fleet declines from 20 percent of today's electricity mix to 15 or 10 percent or less, the US will effectively cede nuclear abroad to China and Russia and undermine the future of nuclear at home. While novel advanced nuclear reactors promise to deliver even cheaper electricity than today's reactors, they will not be developed or deployed in the US if nuclear declines.

Military leaders and national security experts agree that it would be dangerous for the US to cede global nuclear construction to China and Russia. Nuclear power plants are more than large construction projects. No country is as committed to preventing the spread of nuclear weapons as the United States. The US is unusual among nuclear-building nations in imposing special restrictions to prevent proliferation as part of Section 123 of the Atomic Energy Act.

The US Navy and thus national security could be negatively affected by the decline of the US nuclear industry. Navy ships and submarines depend on a US-based nuclear industry supply chain. Many Navy officers who operate US submarines and aircraft carriers create good post-service careers working in the US nuclear industry. If those post-service employment opportunities decline, so too may the appeal of the Navy's nuclear program, which is so vital to national security.

Now is the time to rejuvenate nuclear in the United States and American nuclear competitiveness abroad. America needs to be reminded of Eisenhower's "atoms for peace" vision. That vision is crucial to advancing US national security, spurring economic growth, and creating thousands of high-paying jobs at home and abroad. While the US is rich in natural gas resources, so too are Russia, UAE, and Saudia Arabia, all of which are building nuclear plants at home, with an eye to selling natural gas abroad. As such, abundant natural gas and nuclear can work together to achieve your vision of American energy dominance.

The history of nuclear since 1953 shows that every successful nuclear program in the world relies on three fundamental principles.

First, to be competitive abroad nations must be building nuclear plants at home. Nations seeking to build new nuclear power plants seek partners with significant construction expertise. And such experience comes from a national commitment to, at a minimum, replacing retiring nuclear power plants with equivalent amounts of new nuclear power and, more ambitiously, expanding nuclear energy's share of national electricity.

We should not be scared away from building new nuclear plants simply because of construction delays. History shows that almost all first-of-a-kind (FOAK) designs, including Framatome's EPR and Westinghouse's AP1000, experience construction delays. The good news is that plant construction accelerates as construction crews gain experience.

What matters more than design type is that the US commit itself to replacing the plants it has so it can properly compete abroad. While the US should pursue nuclear plant building with American workers and firms, it may also benefit from partnering with a nuclear-building ally like France, Japan, or South Korea, in order to build efficiently at home, and compete effectively abroad.

Second, nuclear nations must have an "all of the above" approach to technology. Competitive nuclear nations are both building tried-and-true plant designs while developing and demonstrating experimental designs. Over 80 percent of the global market is for large light-water plants being built by the Chinese and Russians. The US must offer a competitive nuclear power plant in every category including large light water plants, small modular plants, and high-temperature designs. In addition to developing and demonstrating novel new designs, the US should accelerate the development, demonstration, and deployment of advanced nuclear fuels, which promise improved performance and lower costs.

Third, successful nuclear nations have the strong support of their federal governments. In the late 1950s, after the US Navy built the first civilian nuclear plant, President Eisenhower and the chairman of the Atomic Energy Commission, who played the role of today's Secretary of Energy, marketed and sold US nuclear reactors around the world. The heads of state of China and Russia do the same today, and any rejuvenated US program must enjoy strong support both from the president as well as from Congressional leaders.

National governments help their nuclear industries win new nuclear plant construction contracts abroad by providing technical and other assistance to the nuclear industry and providing low-cost financing of nuclear plants to buyer nations and utilities. Your administration's successful creation of the Development Finance Corporation has allowed for a minimum of $60 billion in financing for nuclear projects.

The good news is that nuclear brings Americans together. A majority of Americans support nuclear energy. They often do so for different reasons. Some support nuclear because it is affordable and reliable. Others because it produces no air or water pollution. And still others support it for national security reasons. What makes nuclear special is that it has many benefits that a diversity of Americans, and their elected representatives in Congress, have recognized as very important to the US and to the world.

The US should take advantage of its strengths. Nations trust the US more than any other nation when it comes to nuclear energy, and with good reason. The US operates the most nuclear plants in the world and has the largest industry to draw upon. The highly independent Nuclear Regulatory Commission is the gold standard when it comes to government safety regulation, and adopting US nuclear means benefitting from the US's unsurpassed safety record.

The US nuclear industry needs your leadership to grow nuclear at home and sell American nuclear plants abroad. Many things are required and many obstacles need to be overcome. We may need legislation to create incentives for American utilities to build new nuclear reactors, free up capital for financing the construction of American reactors abroad, accelerate the deployment of more efficient fuels, transform the regulatory environment, and demonstrate new reactor designs. But most of all we need your leadership and energy as America's chief nuclear officer.

Now is a critical time for American nuclear power and we thus seek to support your leadership in making America number one again in nuclear energy. We are grateful for your attention and look forward to discussing these ideas with you soon.

Sincerely,

Dr. William J. Madia, Former Director, Oak Ridge National Laboratory and Pacific Northwest National Laboratory

Hermann Grunder, Director Emeritus, Argonne National Laboratory

U. S. Ambassador C. Paul Robinson, Director Emeritus of Sandia National Laboratories

Billy D. Shipp, Ph.D, Laboratory Director, Idaho National Engineering and Environmental Laboratory (Retired)

Charles Casto, Presidential Distinguished Executive, former Regional Administrator (Region III), Nuclear Regulatory Commission

Richard Rhodes, Pulitzer Prize winning author, *The Making of the Atomic Bomb*

John Christensen, President & CEO, Utilities Service Alliance

Daniel Stoddard, Chief Nuclear Officer, Dominion Energy

Paul Fessler, Chief Nuclear Officer, Enrico Fermi Nuclear Generating Station, DTE Energy

William Grover Hettel, Chief Nuclear Officer, Columbia Generating Station, Energy Northwest

Joel P. Gebbie, Chief Nuclear Officer, Donald C. Cook Nuclear Plant, American Electric Power

Jeffrey Wadsworth, Former Director, Oak Ridge National Laboratory, Former CEO, Battelle

Brad Berryman, Chief Nuclear Officer, Susquehanna Steam Electric Station

Andrew Klein, Former President, American Nuclear Society, Oregon State University

Gene Grecheck, Former President, American Nuclear Society

Seth Grae, President and CEO, Lightbridge

Bob Freeman, Framatome, Fuels Division

Heather Matteson and Kristin Zaitz, founders, Mothers for Nuclear

Michael Shellenberger, President, Environmental Progress

Michael Shellenberger is a Time Magazine "Hero of the Environment," Green Book Award winner, and the founder and president of Environmental Progress.

Michael is considered a "climate guru," "North America's leading public intellectual on clean energy," and "high priest" of the environmental humanist movement.
He is an invited reviewer of the next Assessment Report for the Intergovernmental Panel on Climate Change and advises policymakers around the world, including in the U.S., Japan, Taiwan, South Korea, the Philippines, Australia, United Kingdom, the Netherlands, and Belgium.

Michael has helped save nuclear reactors around the world, from Illinois and New York to South Korea and Taiwan, thereby preventing an increase in air pollution equivalent to adding over 24 million cars to the road.

He is a regular contributor to Forbes, The New York Times, The Wall Street Journal, and The Washington Post, and his TED talks ("How Fear of Nuclear Hurts the Environment," "Why I Changed My Mind About Nuclear Power" and "Why Renewables Can't Save the Planet") have been viewed over four million times.
Michael was featured in "Pandora's Promise," an award-winning film about environmentalists who changed their minds about nuclear, and appeared on "The Colbert Report." He debated Ralph Nader on CNN's "Crossfire" and Stanford University's Mark Jacobsen at UCLA .

He is co-founder of Breakthrough Institute, where he was president from 2003 - 2015, and served as an advisor to MIT's "Future of Nuclear Energy" task force.
He is coauthor of visionary books and essays including "An Ecomodernist Manifesto," "The Death of Environmentalism," Love Your Monsters, and Break Through: From the Death of Environmentalism to Politics of Possibility, which was called "prescient" by Time Magazine, and "the best thing to happen to environmentalism since Rachel Carson's Silent Spring" by Wired Magazine. He has been profiled in the New York Times, San Francisco Chronicle, National Review, New Republic, and NPR.
Michael's research and writing have appeared in The Harvard Law and Policy Review, Democracy Journal, Scientific American, Nature Energy, PLOS Biology, The New Republic, and cited by the New York Times, Slate, USA Today, Washington Post, New York Daily News, The New Republic.

Michael has been an environmental and social justice advocate for over 25 years. In the 1990s he helped save California's last unprotected ancient redwood forest, and inspire Nike to improve factory conditions in Asia. In the 2000s, Michael advocated for a "new Apollo project" in clean energy, which resulted in a $150 billion public investment in clean tech between 2009 and 2015.

Michael lives in Berkeley, California and travels widely.

Chairwoman JOHNSON. Thank you very much. Ms. Fransen.

TESTIMONY OF MS. TARYN FRANSEN, SENIOR FELLOW, GLOBAL CLIMATE PROGRAM, WORLD RESOURCES INSTITUTE

Ms. FRANSEN. Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, thank you for inviting me to testify today on the UNEP Emissions Gap Report. My name is Taryn Fransen, and I'm a Senior Fellow at the World Resources Institute, a nonprofit, nonpartisan environmental thinktank. My work focuses on greenhouse gas emissions pathways, and I've been a lead author of the Emissions Gap Report since its third edition in 2012.

The emissions gap refers to the difference between where greenhouse global gas emissions are currently headed and where they need to be headed in order to limit warming to 1.5 to 2° Celsius and avoid its worst impacts. For the past 10 years under the auspices of the Gap Report, the U.N. Environment Programme has convened dozens of researchers from around the world to conduct a rigorous, peer-reviewed assessment of the scientific literature to quantify the gap. And I have to tell you, when I think about the emissions gap, what troubles me is less that people sometimes say unscientific things about it, although that does occur, and more that the actions of too many of our leaders are profoundly out of sync with what the science is telling us we need to do in order to close the gap. I'll tell you a bit about why, and then I'll touch on what other countries are doing and how Congress can help.

Global emissions grew 1.5 percent per year over the last decade to reach a record high last year. Under current policies, emissions are projected to grow by another 8 percent over the coming decade. Without these policies, emissions would have grown even more, so we have made some progress. But slowing growth is not enough. Emissions need to be cut nearly in half by 2030 to limit warming to 1.5 degrees.

We're instead on track to experience warming of around 3 to 3.5 degrees with serious consequences for Americans. Temperatures so far have risen around 1 degree, and that was enough to increase the likelihood of storms like Imelda and Harvey by 2 to 3 times, taking lives and causing billions in damage. With impacts like these and worse projected around the world, you can understand why the Pentagon considers climate change a threat multiplier.

Looking out to 2030, we find that emissions under current policies and pledges are more than 1/3 higher than in 2 degree scenarios and more than double at 1.5 scenarios. This translates to the need for very steep emissions reductions over the next decade and beyond. So to recap, the emissions gap is large, it threatens American prosperity and security, and the window to close it is shrinking.

Several additional pieces of global context should inform how we respond to the emissions gap. First, the emissions gap does not mean that the Paris Agreement isn't working. On the contrary, the gap is smaller with the pledges under Paris than it would be without them.

Second, the gap does not indicate that climate action has stalled everywhere. At last count the number of climate policies around the world had risen to around 1,500. Major emitters are among those taking action. Over the last decade, China has invested twice as much in renewable energy, as has the United States. India is aiming to quintuple its renewable capacity by 2030. But this is only one side of the coin. Even as China greens its own economy, it continues to finance coal infrastructure abroad. In Brazil, deforestation is up 30 percent. And here at home the Trump Administration is in the process of rolling back more than 90 environmental regulations. We will not close the emissions gap unless countries like these change course.

As the world's largest economy with its tremendous diplomatic clout, the U.S. is uniquely positioned not only to go green itself but also to influence other countries to do the same. Congress can do three things to help.

First, Congress should pass ambitious legislation to cut emissions. Recent analysis by the University of Maryland, the Rocky Mountain Institute, and WRI outlines an all-in policy package that can cut U.S. emissions nearly in half by 2030 while generating economic benefits.

Second, Congress should position the U.S. to fully reengage in climate diplomacy and play a strong role in driving the Paris Agreement should it stay in or rejoin. One important avenue is to build on successful, bipartisan efforts to maintain international funding for clean energy, forest protection, and resilience.

Finally, while ambitious near-term action is possible with existing technology, further innovation can broaden our options for ultimately driving net global emissions down to zero. Therefore, Congress should ramp up RD&D (research, development, and demonstration) funding for clean energy and carbon removal.

The current emissions gap puts us on track to experience a dangerous degree of warming. While closing the gap will require actions from all countries, U.S. leadership is especially important. We need to pass ambitious near-term emissions cuts, position the U.S. to conduct robust climate diplomacy, and ramp up investment in RD&D. The alternative—rolling back progress at home and disengaging internationally—will only serve as a convenient excuse for those who would rather avoid action. With only a decade to cut our emissions in half, our future hangs in the balance. Thank you.

[The prepared statement of Ms. Fransen follows:]

Testimony of Taryn Fransen
Senior Fellow, Global Climate Program, World Resources Institute
U.S. House of Representatives Committee on Science, Space, and Technology
Hearing on *An Update on the Climate Crisis: From Science to Solutions*
January 15, 2020

Introduction

My name is Taryn Fransen and I am a Senior Fellow in the Global Climate Program at the World Resources Institute (WRI). WRI is a non-profit, non-partisan environmental think tank that goes beyond research to provide practical solutions to the world's most urgent environment and development challenges. My work at WRI focuses on national and global greenhouse gas emissions pathways and policies; greenhouse gas accounting, monitoring, reporting, and verification; climate change policy in major economies; and the international climate change negotiations.

I have been invited to testify today on the UNEP Emissions Gap Report,[1] which measures the difference between where global greenhouse gas emissions are currently headed and where they need to be in order to limit warming to 1.5°C (2.7°F) and avoid the worst impacts of climate change. Over the past 10 years, the emissions gap has become one of the key metrics for measuring our collective progress on addressing climate change. I have been a lead author of the Emissions Gap Report since its third edition in 2012, and I co-chaired a special assessment on national climate change pledges during the lead-up to the 2015 Paris Agreement.[2]

I will focus my testimony on three main points:

Summary
(1) The emissions gap is large, and the window to close it is shrinking quickly. Under current policies and pledges, the planet is on track to warm by 3°C to 3.5°C (5.4°F to 6.3°F), at great peril to the American people, our communities, and our economy.
(2) Countries around the world are taking action to reduce emissions, but all of us need to do much more. Prospects for the top emitters to step up would be much greater if the federal government of the United States — the world's largest economy and second-largest emitter — would get off the sidelines and go all in on climate action.
(3) Congress can help close the emissions gap by passing ambitious legislation to reduce emissions, investing in research and development, and positioning the United States to fully re-engage in the Paris Agreement.

About the UNEP Emissions Gap Report

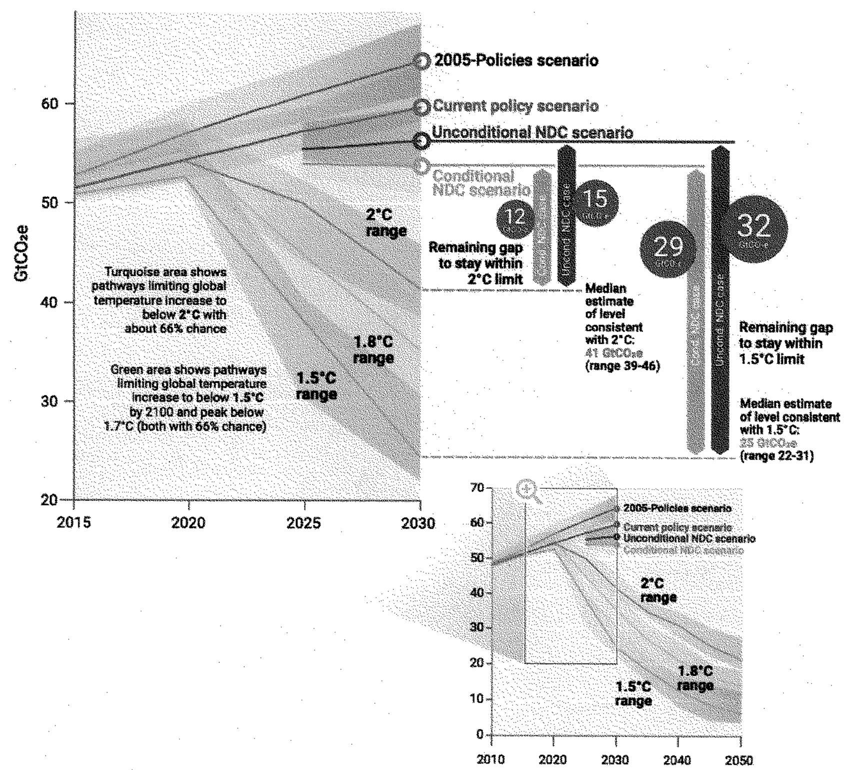
Under the auspices of the Emissions Gap Report, the UN Environment Program convenes dozens of scientists and researchers from around the world to assess the scientific literature and address key questions related to greenhouse gas emissions trends. Core among our tasks is to quantify the "emissions gap" — the difference between where global greenhouse gas emissions are currently headed and where they need to be to avoid the worst impacts of climate change. Calculated on an annual basis

[1] https://www.unenvironment.org/resources/emissions-gap-report-2019
[2] UNEP, "Emissions Gap Report 2015."

since 2010, the emissions gap is an important metric to monitor global progress on climate change mitigation. The Emissions Gap Report is advised by a Steering Committee of senior international experts and undergoes a rigorous peer review process. The 2019 report drew on the expertise of 57 authors from 33 institutions across 25 countries and was reviewed by over 40 additional experts.

In summary, the emissions gap compares projected emissions in a given year under different scenarios (Figure 1). The most recent Gap Report considered 2030 emissions in scenarios associated with current policies and with the commitments countries pledged under the Paris Agreement (known as nationally determined contributions, or NDCs). It then compared those emissions against pathways for limiting warming to 1.5˚C (2.7˚F), 1.8˚C (3.2˚F), and 2˚C (3.6˚F). The emissions gap is the difference in 2030 emissions between the policy scenarios and the different temperature pathways.

Figure 1 | Global GHG emissions under different scenarios and the emissions gap by 2030



Source: UNEP, "Emissions Gap Report 2019."

Where are global greenhouse gas emissions today, and where are they headed?

Global greenhouse gas emissions grew 1.5 per cent per year over the last decade to reach a record high of 55.3 $GtCO_2e$ in 2018.[3] Emissions have grown every year since the 2008 financial crisis, leveling off only slightly in 2015 due to major declines in coal use in China and the United States.

Under policies currently being implemented around the world, emissions are projected to grow by another 8 per cent over the next decade, reaching 60 $GtCO_2e$ in 2030. However, if countries deliver on their pledges under the Paris Agreement — which will require implementing additional policies — then by 2030, emissions will instead return to about the same level as in 2018. Without current policies, emissions would have grown by 16 per cent by 2030, so both of these scenarios do represent some progress. But it is nowhere near enough. Neither of these scenarios would meaningfully reduce emissions by 2030, when in fact they need to be cut almost in half by that time to limit warming to 1.5°C (2.7°F).

The current trends put us on track to experience an estimated 3°C to 3.5°C (5.4°F to 6.3°F) of warming.[4] The consequences for Americans are potentially severe. To date, average annual temperatures have risen by just 1°C (1.8°F) across the contiguous United States, and already, the average heat wave season in many cities is now 40 days longer than it was 50 years ago, heavy precipitation events have become more frequent and intense across most of the country, and drier conditions have combined with warming to contribute to an increase in large forest fires in the West and Alaska.[5] These and other impacts will become more severe with every additional fraction of a degree of warming, potentially to the tune of 3.6 - 4.2 per cent of GDP.[6]

How much do global greenhouse gas emissions need to be reduced to avoid the most dangerous impacts of climate change?

Projected emissions in 2030 under current policies and pledges are more than one-third higher than the median in scenarios consistent with limiting warming to 2°C (3.6°F), and more than double the median in scenarios consistent with limiting warming to 1.5°C (2.7°F) (Table 1). This translates to reducing emissions by 2.7 per cent per year to limit warming to 2° C (3.6°F), and by 7.6 per cent per year on average through 2030 for 1.5°C (2.7°F). If we had begun reducing emissions a decade ago, we could have pursued this transition somewhat more gradually, but now we have given ourselves no choice other than swift action.[7]

To recap: The emissions gap is large, it threatens American prosperity, and the window to close it is shrinking quickly.

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[3] 2018 emissions were 55.3 $GtCO_2e$ including land use, land-use change, and forestry (LULUCF) and 51.8 $GtCO_2e$ excluding LULUCF.

[4] Median values of studies estimating global average temperature increase under various policy scenarios are as follows: 3.5°C for current policies, 3.2°C for unconditional NDCs, and 3°C for conditional NDCs (that is, those NDCs that are contingent on certain conditions, such as international financial support).

[5] USGCRP, "Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (Eds.)]."

[6] Hsiang et al., "Estimating Economic Damage from Climate Change in the United States."

[7] If global emissions had begun to fall a decade ago, they would need to fall 1.7 per cent per year to limit warming to 2° C (3.6°F) and 3.3 per cent per year to limit warming to 1.5° C (2.7°F).

Table 1 | Projected Emissions and Size of Emissions Gap in 2030 ($GtCO_2e$, median, 10th percentile and 90th percentile)

Scenario	2030 Emissions	2030 Emissions Gap	
		Below 2℃ (3.6℉)	*Below 1.5℃ (2.7℉)*
Current policy	60 (58-64)	18 (17-23)	35 (34-39)
Unconditional NDCs[8]	56 (54-60)	15 (12-18)	32 (29-35)
Conditional NDCs	54 (51-56)	12 (9-14)	29 (26-31)
Below 2°C	41 (39-46)		
Below 1.5°C	25 (22-31)		

Source: UNEP, "Emissions Gap Report 2019."

The emissions gap in the global context

Several pieces of global context should inform the United States' response to the emissions gap.

First, it is important to understand that the persistence of the emissions gap does not mean that the Paris Agreement is not working. On the contrary, the emissions gap is smaller than it would be without the pledges made under the Agreement. Moreover, negotiators in Paris were well aware of the gap between countries' initial commitments and the agreed temperature limits, so they included a mechanism whereby countries would ratchet up their commitments every five years. This year — 2020 — marks the first cycle, and 79 countries have already signaled their intent to enhance their pledges.[9]

Second, the emissions gap does not indicate that climate action has stalled globally. At last count, 139 countries had framework climate legislation in place, and the number of climate policies in action throughout the world had risen since the Paris Agreement to around 1,500.[10] The expansion of climate policies over the past 15 years has shrunk the emissions gap by about 6 per cent compared to what it would otherwise be.

Major emitters — including those with cumulative and per-capita emissions far lower than those of the United States[11] — are among those taking action. To highlight two key examples:

China has continued to ramp up investment in renewable energy, investing far more than any other country. Over the past decade, it committed $758 billion to renewable energy capacity — more than double the U.S. sum of $356 billion.[12] China is also going big on electric vehicles (EVs). Having announced its intent to phase out internal combustion engine vehicles,[13] China is aiming for 20 per cent of sales to

[8] The Gap Report estimates global emissions under unconditional NDCs, which are the commitments countries pledge to achieve unilaterally, and under conditional NDCs, which are typically more ambitious pledges contingent on certain conditions, such as international financial support.

[9] https://www.climatewatchdata.org/2020-ndc-tracker

[10] Nachmany and Setzer, "Global Trends in Climate Change Legislation and Litigation: 2018 Snapshot."

[11] 2016 per capita emissions in the United States, China, and India were 18.1, 8.4, and 2.4 tons of CO_2-equivalent (Climate Watch).

[12] Frankfurt School-UNEP Centre/BNEF, "Global Trends in Renewable Energy Investment 2019."

[13] https://www.independent.co.uk/news/world/asia/china-petrol-diesel-car-ban-gasoline-production-sales-electric-cabinet-official-state-media-a7938726.html

be EVs by 2025, equivalent to 7 million vehicles.[14] The city of Shenzhen (population 12.5 million) has already switched to 100 per cent electric buses[15] and is in the process of electrifying its taxi fleet.

India is also pursuing an ambitious clean energy future, aiming to quintuple its renewable capacity to 450 GW by 2030,[16] even as it aims to bring reliable electricity to 100 million people who do not yet have it.[17]

Both countries are on track to achieve their Paris Agreement pledges and have indicated their intent to adopt stronger targets.[18]

But finally, unfortunately, the surge in clean energy is only part of the picture. Even as China greens its own energy supply, it continues to finance fossil fuel infrastructure abroad, committing over $20 billion to coal-fired power in South and Southeast Asia and Africa.[19] Elsewhere, in Brazil, deforestation is up by 30 per cent as President Jair Bolsonaro scales back efforts to fight illegal logging, farming, and mining.[20] And of course, here at home, the Trump administration is in the process of rolling back more than 90 environmental regulations.[21] We will not close the emissions gap unless countries like these change course.

The imperative of U.S. leadership to close the emissions gap

As the world's largest economy, and with its tremendous diplomatic clout, the United States is uniquely positioned not only to go green itself, but also to influence other countries to do the same. There are three things that Congress can do to help leverage this potential.

First, Congress should pass ambitious legislation to cut greenhouse gas emissions in line with what the Emissions Gap Report says is needed. The good news is that recent analysis by the University of Maryland, the Rocky Mountain Institute, and WRI shows that an "all-in" policy package that leverages state and local leadership combined with ambitious new federal action can cut U.S. emissions nearly in half by 2030, generating $26 billion to $58 billion in health benefits alone.[22] Such a strategy would entail decarbonizing the electricity sector; electrifying and improving the efficiency of buildings, transport, and industry; and enhancing the carbon storage potential of forests, farms, and coastal wetlands.

Second, Congress should position the United States to engage effectively in international climate diplomacy and play a strong role in driving the Paris Agreement forward, should it remain a Party or rejoin in the future. One important avenue is for Congress to build on its successful bipartisan efforts to maintain international funding for clean energy, forest protection, and resilience. Funding like this

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[14] https://www.reuters.com/article/us-china-autos-electric-idUSKBN17R086?feedType=RSS&feedName=environmentNews

[15] https://www.wri.org/blog/2018/04/how-did-shenzhen-china-build-world-s-largest-electric-bus-fleet

[16] https://www.narendramodi.in/pm-modi-s-remarks-at-summit-on-climate-change-546575

[17] IEA, IRENA, UNSD, WB, WHO, "Tracking SDG 7: The Energy Progress Report 2019."

[18] https://www.fmprc.gov.cn/mfa_eng/wjdt_665385/2649_665393/t1676859.shtml; https://www.mea.gov.in/bilateral-documents.htm?dtl/31755/IndiaFrance+Joint+Statement+on+Visit+of+Prime+Minister+to+France+2223+August+2019

[19] https://www.theguardian.com/world/2019/apr/25/belt-and-road-summit-puts-spotlight-on-chinese-coal-funding

[20] https://www.nytimes.com/2019/11/18/world/americas/brazil-amazon-deforestation.html

[21] https://www.nytimes.com/interactive/2019/climate/trump-environment-rollbacks.html

[22] The America's Pledge Initiative on Climate Change, "Accelerating America's Pledge: Going All-In to Build a Prosperous, Low-Carbon Economy for the United States." By N. Hultman, C. Frisch, L. Clarke, K. Kennedy, P. Bodnar, P. Hansel, T. Cyrs, M. Manion, M. Edwards, J. Lund, C. Bowman, J. Jaeger, R. Cui, A. Clapper, A. Sen, D. Saha, M. Westphal, W. Jaglom, J.C. Altamirano, H. Hashimoto, M. Dennis, K. Hammoud, C. Henderson, G. Zwicker, M, Ryan, J. O'Neill, E. Goldfield.

supports national security[23] and can help U.S. businesses to benefit from an estimated $23 trillion in low-carbon investment opportunities in emerging markets,[24] in addition to ensuring that the United States fulfills longstanding international commitments.

Finally, while ambitious near-term actions are possible with existing technologies, further innovation in clean technology can broaden our options for ultimately driving net global emissions down to zero, which we must achieve around mid-century to limit warming to 1.5°C. Innovation can also reduce costs and improve the competitiveness of U.S. businesses. Therefore, Congress should ramp up research and development funding across the power, transport, buildings, industry, and land sectors, as well as technology-based carbon removal.[25]

Conclusion

The current emissions gap puts us on track to experience warming in the range 3°C to 3.5°C (5.4°F to 6.3°F), exacerbating the impacts from wildfires and extreme weather already being felt around the country, and threatening our economy and national security. To close the gap, we need to cut global emissions roughly in half by 2030. While this will require ambitious action from all countries, U.S. leadership is particularly important. To lead the way, we need to: pass ambitious near-term cuts to U.S. emissions, generating economic and health benefits in the process; position the United States to engage in robust climate diplomacy, including via the Paris Agreement; and ramp up investment in research and development. The alternative - rolling back progress at home and disengaging internationally - will only serve as a convenient excuse for those who would rather avoid action. With only a decade to cut our emissions in half, it is not an exaggeration to say that our future hangs in the balance. Thank you.

[23] https://www.wri.org/blog/2017/02/us-climate-finance-great-deal-nation-and-world

[24] IFC, "Climate Investment Opportunities in Emerging Markets: An IFC Analysis."

[25] https://www.wri.org/blog/2018/12/wanted-325-million-federal-rd-jumpstart-carbon-removal

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Taryn Fransen

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In 2018, Ms. Fransen served as Senior Policy Advisor on the Global Climate Action Summit for the Office of the Governor of California. From 2011-2017, she led WRI's Open Climate Network, a coalition for ambition and transparency on climate action that focused most recently on strengthening countries' commitments under the Paris Agreement. Previously, she managed the Greenhouse Gas Protocol's efforts to build greenhouse gas accounting capacity in developing countries, including Brazil, China, India, Mexico, and the Philippines. Ms. Fransen has also contributed to WRI's research on climate finance and on greenhouse gas measurement, reporting, and verification.

Before joining WRI, Ms. Fransen worked for the United Nations Foundation and the Pew Center on Global Climate Change (now C2ES) and provided research support to a range of clients in the environmental community, including World Wildlife Fund, the Tropical Science Center, and the Stockholm Environment Institute.

Ms. Fransen served on the board of directors of the Greenhouse Gas Management Institute from 2016 to 2019. She holds an M.S. and B.S. in Earth Systems from Stanford University and is pursuing doctoral studies in the Energy and Resources Group at the University of California, Berkeley.

Chairwoman JOHNSON. Thank you very much.

We now have completed the testimony of our witnesses, and at this point we will begin our first round of questions. And I recognize myself for 5 minutes.

The climate change crisis is the largest existential threat that we face today and has long-term implications that will impact future generations. In order to foster climate resilience and sustainability development, there must be sustained, effective coordination and ambitious efforts for both adaptation and mitigation. I've often called this Committee "the Committee of the Future" because many impactful scientific discoveries have come from or were supported by agencies within our jurisdiction.

Given this long history of robust scientific investment, I'd like each of you, time permitting, to comment on what are the most urgent mitigation adaptation needs, and what are the greatest barriers to achieving these goals? What investments should this Committee be making in Federal research and development efforts in the immediate future or further develop and implement effective mitigation and adaptation strategies? And finally, what scale should these investments be made? We'll start with our first witness.

Dr. MCELWEE. Great. Thank you for that question. You're absolutely right that we need to focus on both mitigation and adaptation. We're already seeing climate impacts at the degree of temperature change a little bit under 1° C that we're already at. We're committed to more, so adaptation is crucial.

For the land sector, one of the really interesting things is that things that we do for mitigation also can get us adaptation benefits. We get two in one. So, for example, if you think about increasing soil's ability to store carbon, that gives us mitigation benefits. It also gives us adaptation benefits. I mentioned in my written testimony that there's evidence that farmers in the midwest who have been using cover crops and no-till techniques for a while, which encourages healthy soils, were actually more likely to be able to plant despite all of the terrible unseasonable extreme rainfall events we had in the spring. So we get some mitigation benefits and we get some adaptation benefits with some of our actions.

And the great news at least on the land sector is a lot of the things that we can do we don't need to wait for technological breakthroughs. For sure there are things that we can be doing that would require science investment. I can think of things around genetic engineering in terms of crops to make them more resilient, adaptive. There's some really interesting work that's going on, too, for example, get grains to be able to fix nitrogen just like our legumes do. There's some really fascinating things that are going on. But at least for the land sector we don't have to wait for that. There's things that we can do now that get us both adaptation and mitigation.

Dr. MURRAY. Regarding mitigation, first up, there's a group called the High-level Panel, which has written a report, and they make several recommendations that I echo, sort of ocean-based renewable energy, very important. You can look at the transportation sector out in the oceans; look at fisheries, aquaculture, so on; try some study of advanced methods for carbon storage in the seabed.

But particularly relevant to the House I want to draw attention to is sort of the blue carbon, coastal marine ecosystems role. As you're aware, there's a bipartisan bill, *Blue Carbon for Our Planet Act*, and that's a real strong step in the right direction of making a difference in the ocean world.

Regarding investments in research, as I spoke about, really needing to step up the degree and the amount of our ocean observations, again, I want to emphasize the importance that has for land. For example, there are some colleagues of ours at Woods Hole Oceanographic who have been studying salinity out in the open ocean. As fresh water evaporates from the ocean, it's going to land on land, turn into snow and ice on land, and we can actually measure how much and predict much better what's going on on land by measuring salinity out at sea. So there are very strong ocean-land linkages.

In terms of scale, I'm not here before you to recommend dollar values other than recommend large scale. This is the time. It's a big planet. The ocean is big. These are big problems. We've made sufficient progress to date maximizing what we're able to do with the resources provided to us, but it's a huge ocean and a large system. We need to tremendously increase the scale of investment. Thank you.

Dr. STELTZER. Thank you. I'll focus on four points, three focused on adaptation first. Let's make sure that the local water managers across the U.S. have the resources they need to know how much water they have and when and how that water is filling reservoirs and streams. A lot of times the way that they make their decisions they don't have all the information they would need, and we could make sure that they have those resources. That would be an adaptation approach.

The second one is that we can reduce other stressors so where and how do you develop a plan for the timeline and flexibility that you need to be adaptive and responsive to change, you make sure that you don't have 10 things that are stressful all at once.

So what are some of those other stresses we can manage for? We can protect mountains and snowpack from dust. Dust on snow accelerates the rate that snow melts so much so that it's almost shocking when you see the numbers because it's 30- to 60-day timelines that the snow has gone first. We know that that dust is U.S. dust. We know that that dust is not coming from China. You can characterize the isotopes in the dust and see that it's U.S. dust, and so actions that we take across the western U.S. to manage for dust across the Great Plains of the U.S. to manage for dust.

The third one is increasing knowledge, the diversity of knowledge systems that we employ, and that means bringing in diverse people to these spaces and to all spaces where we're doing science. I teach at a majority minority-serving institution. Thirty-eight percent of the students at Fort Lewis College are Native American descent. There's a tuition waiver in place that provides for that. I have learned more from my students in 11 years of education, co-learning with them, and where and how can we create spaces that remove barriers to a more inclusive space for the diversity of wealth and knowledge within this country.

And the fourth one that I wanted to make is about mitigation. I recently on Monday night learned about the *CORE Act*. That's something Congress has already supported, and I want to thank you for that. That is fantastic to look and see where and how we can put lands into new types of characterizations to manage for mixed use of land in new ways. Thank you for what you've done.

Chairwoman JOHNSON. Thank you very much. I'm out of time, but I'm going to ask Mr. Shellenberger and Ms. Fransen if you will submit your response to my question if we don't get around to a second round of questions. And I thank you.

I now recognize Mr. Lucas.

Mr. LUCAS. Thank you, Madam Chair.

Mr. Shellenberger, just 10 years ago the idea that the United States would be a net exporter of oil and gas was almost unthinkable, and I think the last time we did that perhaps was about the time of my birth. And I would note to you my grandchildren believe that's a very long time ago.

Then the shale revolution came along, led by Federal investments in basic research, and American industry made it a reality. And I've seen firsthand in my home State of Oklahoma how it all started with research and development at DOE's national labs followed by tax credits, market reforms, partnerships that led to private investment and innovation. Today, we're reducing emissions around the world with cleaner, more efficient American natural gas.

Now, that said, it's my hope that nuclear power can follow the same pathway and contribute clean, reliable power around the world. Where are we as a Nation in advanced nuclear development, and how can we kickstart nuclear energy in the same manner as the shale revolution?

Mr. SHELLENBERGER. Thank you very much for that question. I actually did a significant amount of research on the historical origins of the shale revolution. And while there's a number of similarities, there's important differences as well. Obviously, you know, the biggest one with nuclear is just that it is a dual-use technology, and so the main obstacle to nuclear's expansion has always been the fears of its use to make weapons. And that's the main reason that I think most progressives and Democrats are concerned about it. That was the nature of my opposition to nuclear as a young man.

I think where it's similar is the shale revolution occurred in the context of significant demand for natural gas. Natural gas has always been viewed as a superior fuel to coal just because of it burning much cleaner. It has half the carbon intensity of coal burning. So there was always a significant amount of demand for natural gas. We don't have that same demand for nuclear just because it's significantly less popular.

I think the other big difference then is that when you look at what's actually succeeded for nuclear both in the United States historically and with what Russia and China are doing now is that you have heads of state directly selling nuclear power plants to other heads of state. It's a highly centralized activity. You have one or two firms. In the United States it was General Electric and Westinghouse. In China and Russia right now it's a single State-owned firm. If somebody calls up the Department of Energy in the United States and says I want to build an AP1000, which are the reactors that we're building out at Vogtle in Georgia, there's really not anybody—it would—you think it would be Bechtel, but Bechtel is only involved in that Vogtle project. They're not actively selling nuclear.

So I think we've overemphasized the different nuclear technology designs, which just comes from a community that's very technically oriented. But what makes nuclear successful is when it's really embraced and pushed by both the White House and Congress. And we've got to be building nuclear power plants in the United States, or we're simply not going to be competitive abroad.

Mr. LUCAS. Expand just a little bit more on the concept about the antinuclear sentiment, which really first I guess came around in the 1960s and remains today? Can you talk about what's driving that fear and how the relationship to the broader discussion and some of the predictions about climate change, how all this interacts?

Mr. SHELLENBERGER. Nuclear is special, so we sometimes say we need all these different solutions for climate change—carbon capture and storage, solar, wind, and nuclear—but nuclear is unlike the rest of those. This is a revolutionary technological development both in the dual nature of the technology, the incredible energy density of it, and I think that really we suffered—I think the whole human race suffered a kind of trauma and shock when we invented the bomb in the 1940s.

And then there was a lot of enthusiasm after "Atoms for Peace" in 1953 that we would sort of redeem ourselves for having invented such a horrible weapon with nuclear energy, so there's a lot of enthusiasm in the 1950s. But ultimately what happened is that the fears of nuclear weapons transferred themselves—just to use a bit of psychological jargon—onto power plants, and antinuclear weapons activists somehow imagined that shutting down nuclear power plants would rid the world of nuclear weapons.

That's really never gone away. In fact, the apocalyptic concerns that we see around climate change today began with apocalyptic concerns around nuclear weapons. And as the cold war ended, really the people that were looking for some kind of secular apocalypse found it with climate change, which is why I think so much of the climate activists and environmentalists community is opposed to nuclear.

So when you kind of get I think to the Chairwoman's question, what is the main obstacle to significant accelerated decarbonization? It's getting over our fear of this technology. Nuclear energy is a true blessing. It emits almost zero air and water pollution. In my view it's the only true replacement of fossil fuels. Renewables are just too energy-dilute and intermittent to be able to do that, so we need some kind of a shift in consciousness, and I think congressional leadership and White House leadership is really important to that.

Mr. LUCAS. Thank you, Mr. Shellenberger. And, Chair, as I yield back, in an indirect way I appreciate the endorsement of the panel about the conservation provisions in the 2014 and 2018 farm bill. After all, we've worked since 1935 on the land-use questions to try and preserve our resources. I yield back, Madam Chair.

Chairwoman JOHNSON. Thank you very much. Mr. Lipinski.

Mr. LIPINSKI. Thank you, Madam Chair. And thank you for holding this hearing today.

This has been an issue—I was just talking to Mr. Perlmutter to say that I've been around here for a long time. It's an issue we've been talking about, I've been active on, and unfortunately we haven't done a whole lot to really address, you know, climate change.

One thing that the U.N. Emissions Gap Report, one of the opportunities that the report recommends for the U.S. is introduction of carbon pricing. And that's something that I actually joined two Republicans 11 years ago in introducing a carbon pricing bill. And that's something that I really think that we need to take a very good look at as a way to do this and something that I especially encourage my Republican colleagues to take a look at as a market solution. We're putting a price that really is there. You know, carbon and all climate change gases do have an externality price that is not realized. And I think the government should put that on, take all that money, and that bill I introduced 11 years ago and the one I have this year gives all the money back to the Americans. So we have that opportunity.

I really think we should fund ARPA-E (Advanced Research Projects Agency-Energy) to a much greater extent to help.

I also introduced a bill, the *Challenges and Prizes for Climate Act of 2019*, to spur innovation. It directs the Secretary of Energy to establish climate solutions challenges in a variety of areas critical to addressing climate change, including carbon capture and beneficial use, energy efficiency, energy storage, climate resiliency, and data analytics for climate modeling and forecasting.

So I want to ask Ms. Fransen, do you think such a prize incentive would be beneficial in spurring additional interest in the area of research and development to develop climate solutions?

Ms. FRANSEN. Thank you for the question. So you've touched on I think two very important tools that can be part of a comprehensive policy package to address climate change. And to put both of those in a little bit of context, I think there are two things that we need to be doing at the same time. One is taking near-term action with existing technologies to generate very ambitious emissions cuts in this decade. If we don't do that alongside R&D (research and development) and innovation at the same time we will not solve this problem. It would be too long to wait. So we need to do both of those things just to be very clear.

That being said, ultimately we need to drive global emissions down to net zero. We know how to do that in—across many sectors with many solutions, but the more that we can innovate and the more that we can support R&D, the broader and more cost-effective our suite of options will be. So absolutely incentives for innovation are a key part of this. Incentive for many of the innovations that you mentioned, including efficiency, carbon capture and storage, which we need to put on any remaining fossil fuels and industrial applications, and so on to get us to zero carbon energy as soon as possible. Thank you.

Mr. LIPINSKI. Thank you. I wanted to ask Dr. Murray, can you comment on whether we should expect any kind of similar impacts on the Great Lakes as on the oceans or any other impacts that you want to talk about that climate change is going to have in the future on the Great Lakes?

Dr. MURRAY. That's a very good question. Personally, my expertise is not in the Great Lakes per se, but I can speak on the fact that, as precipitation patterns change throughout the country even in the interior driven by the ocean, driven by weather, driven by other matters, the hydrology of the area is going to be changing. I do know that recently the Great Lakes lake level has been changing quite dramatically, and so on. But overall the Great Lakes are of course very important for our commerce and other matters. But the main driver on Great-Lake change is going to be the changing precipitation patterns.

Mr. LIPINSKI. Thank you. I will yield back instead of going on with my last 15 seconds. Thank you.

Chairwoman JOHNSON. Thank you very much. Mr. Brooks.

Mr. BROOKS. Thank you, Madam Chair.

I have been looking at a study entitled, "Fossil Carbon Dioxide Emissions of All World Countries" 2018 report, and that's a publication of the Office of the European Union. So to the extent these numbers err, it's European Union's credit.

And that report looks at a number of different countries, how much of the carbon emissions they are responsible for, and what their internal trendlines have been. And so I look at the European Union collectively from the year 1990 to 2017, and they, according to the European community, have had a drop by 19 percent in carbon emissions. And the European Union is responsible for 10 percent of all world carbon emissions. So according to the European Union, they're doing pretty good.

Then you look at the United States of America in that same report. The United States of America is responsible for 14 percent of all the carbon emissions. Over this 17-year period of time, the United States has had 0.4 percent increase in carbon emissions. That's over the entire 17-year period. Since 2007, over the last decade of this report, the United States' carbon emissions had dropped 14 percent. So it appears that the United States has held its own and more recently is actually cutting its carbon emissions.

Then you move to India and China. India is responsible for 7 percent of the total carbon emissions. Their carbon emission output has increased by 305 percent over that 17 years. China is responsible for 29 percent of the total world's carbon emissions, more than double the United States of America and almost triple the European Union. And over that 17-year period, their carbon emissions have gone up 354 percent.

And so my question to each of you, 30, 45 seconds apiece, is what do you propose to stop India and China from emitting so much carbon? Dr. McElwee?

Dr. MCELWEE. Well, the reason why we have global accords like the Paris Agreement is precisely for this problem. It's a global problem, and everybody contributes to it and everybody can be part of the solution.

Mr. BROOKS. Well, did those agreements force China and India to cut anything?

Dr. MCELWEE. Right. The Paris Agreement is——

Mr. BROOKS. Well, not right——

Dr. MCELWEE [continuing]. Primarily voluntary.

Mr. BROOKS [continuing]. That's a question.

Dr. MCELWEE. Yes, it's primarily voluntary pledges, so it doesn't——

Mr. BROOKS. OK. It's voluntary.

Dr. MCELWEE [continuing]. Require that.

Mr. BROOKS. So I'm asking what can we do to force them to cut their carbon emissions inasmuch as they are the principal problems of the increases in carbon emissions over the last 17 years?

Dr. MCELWEE. Well, we can also talk about historical emissions over a longer time period in which case the U.S. would be more responsible. But your point is exactly right that we have tools potentially to help these countries reduce their carbon intensity. This can rely on exporting some of our technologies that could help them reduce carbon intensity and carbon growth, but that requires us to take a leadership role. And so having us be part of the Paris accord——

Mr. BROOKS. OK. I heard encouragement, but I didn't hear anything that would actually cause them or force them to do it.

Dr. Murray?

Dr. MURRAY. I'm going to pass respectfully on your question, sir. I'm not an energy specialist nor a specialist on China or India or such matters that you asked.

Mr. BROOKS. Dr. Steltzer.

Dr. STELTZER. I'm not an expert in international diplomacy, but I rarely take the approach of forcing my will on another person. I know that I can engage in constructive conversations, which I believe is the call and the ask of the meeting today.

I did go to China this summer in order to understand the Qing-Zang Tibetan Plateau, the third pole of our planet, and what I experienced by being in China for 10 days straight with Chinese was incredible. They were——

Mr. BROOKS. OK. That's nice——

Dr. STELTZER [continuing]. Welcoming——

Mr. BROOKS [continuing]. But that's not answering my question. I have limited time.

Dr. STELTZER. It is building relationships.

Mr. BROOKS. Mr. Shellenberger, can you please give a response in the little time we have left?

Mr. SHELLENBERGER. We should absolutely not force poor countries to stay poor, which is basically what that would require. I mean, moving from wood and dung to burning fossil fuels is environmental and human progress. It would be unethical to punish poor countries and force them to stick with wood and coal. The reductions in emissions in the rich world are not done because we sacrificed. It's because we moved to natural gas. China and India will follow that same pathway by moving to natural gas. But it would be crazy and immoral to force poor countries to stay poor.

Mr. BROOKS. My time is expired. I'm sorry, Ms. Fransen. Maybe if the Chairwoman will allow you to answer, you may, but it seems to me that the major problem we have is China and India, and I didn't hear any answer as to how we're going to be able to cause them to control their problem that is emitting so much carbon. Thank you.

Chairwoman JOHNSON. Thank you. Ms. Bonamici.

Ms. BONAMICI. Thank you to the Chair and the Ranking Member, and thank you to all of our witnesses today for your expertise. We know that every person on the planet benefits from a healthy ocean and a stable cryosphere, and unfortunately, there are some dire findings in the IPCC Special Report on the ocean and cryosphere in a changing climate. We know that the effects are being seen not only in the remote deep ocean floor but also in the most pristine arctic and mountain regions.

But there's also opportunity. The same week that the IPCC released its Special Report, the High Level Panel for a Sustainable Ocean Economy released another report demonstrating how we can capture the power of the ocean and estuaries for effective climate mitigation. I am the Co-Chair of the House Oceans Caucus and also serve on the Select Committee on the Climate Crisis, and I'm committed to bold science-based policies that will reduce emissions and transition us to a 100 percent clean energy economy.

And last year after the IPCC report I led a group introducing a resolution that supports those findings. And then also thank you, Dr. Murray, for mentioning the bipartisan *Blue Carbon for Our Planet Act*, which I just introduced with Representatives Posey, Beyer, and Mast to strengthen Federal research on blue carbon and protect and restore coastal blue carbon ecosystems. We know that the oceans can be part of the solution.

So, Dr. Murray, the IPCC Special Report demonstrated that some of the effects of the climate crisis on our ocean like ocean acidification, hypoxia, sea-level rise, and warming waters are already locked in. So in the short term, where are the Federal investments in ocean data and monitoring needed to support our frontline coastal communities in adapting to the climate crisis? And also, how can Federal policy better support those opportunities for the ocean like marine energy and blue carbon so we can use the ocean as part of the solution to mitigate the climate crisis?

Dr. MURRAY. So thank you for that question, and also, Congresswoman, thank you for your support in your State of Oregon, Oregon State University with the regional class research vessels that they are investing in through the National Science Foundation, for example. That's precisely one of the many types of infrastructure that this country is doing very well to support.

There are a number of infrastructure needs in the ocean-observing realm to gather this critical data to address the questions that you ask, in addition to the ships and other mechanical hardware-type aspects, and this also refers back to Congressman Lipinski's earlier comments about ARPA-E and technological advancements. The ocean community is rapidly evolving and including very complicated ways of looking at the very large amounts of data that we're looking at with artificial intelligence and machine learning. We need technological advancements in batteries because the things that we have out in the ocean, deep-sea need power, so we need smaller batteries that are more powerful. And so innovation, investments throughout the sectors are going to help everything that we need to do in that range.

Regarding some other aspects, overall, the image I want to get across here is that we have such high data-gathering density on land. And you look at the tremendous advances that the National Weather Service has been able to make from Federal advances. We don't have anything near that scale for the oceans.

Ms. BONAMICI. Right. We——

Dr. MURRAY. That's the direction——

Ms. BONAMICI. And I really don't want to cut you off, but I want to get a question in to Dr. Steltzer as well.

Dr. MURRAY. Thank you.

Ms. BONAMICI. Thank you, Dr. Murray.

Dr. Steltzer, in your testimony you noted that abrupt permafrost thaw is a sudden destabilizing process in the Earth's climate system and that the only way to slow the process is to keep the Earth below 1.5 relative to pre-industrial times. Ultimately, if we fail to reduce emissions below 1.5, then widespread thaw of permafrost could ultimately release tens to hundreds of billions of tons of carbon dioxide and methane into the atmosphere. So you suggested that every 10th of a degree matters. Can you explain why that number is significant and what the potential opportunities are to incorporate the cryosphere into our adaptation and mitigation strategies? In 40 seconds.

Dr. STELTZER. In 40 seconds. A 10th of a degree, the freezing point of water is at 0° Celsius, 32° Fahrenheit, so every 10th of a degree that you go over that you thaw something, you melt—you thaw permafrost, you melt ice. And stored carbon that is frozen, is carbon that isn't accessible by microbes.

The work that I do in the Arctic has always been on the plant side to understand where and how plants pull carbon dioxide out of our atmosphere and put it into the soil. The microbes win every time. It's basic physiology of the organisms that are involved.

So the second piece in probably 10 seconds was?

Ms. BONAMICI. Was can you explain what are the opportunities to incorporate the cryosphere into our adaptation and mitigation strategies?

Dr. STELTZER. Snow. I only had a second.

Ms. BONAMICI. Thank you so much. My time is expired. I yield back. Thank you, Madam Chair.

Chairwoman JOHNSON. Mr. Weber.

Mr. WEBER. Thank you, ma'am. Dr. Murray, I want to ask you a question in response to Mo Brooks' question that you said you really weren't an expert in, but you are an expert more so in how the climate is affecting the oceans. Is that kind of accurate? So assuming that the percentages that he quoted from the European Union are correct, with China polluting that much, do you think that negatively impacts the ocean?

Dr. MURRAY. Most definitely. The carbon dioxide molecule knows no political boundaries. It's being cycled through our atmosphere into the ocean and into our plants.

Mr. WEBER. OK. Well, then you might want to do a little digging on China. I want to go to Mr. Shellenberger next.

Mr. Shellenberger, there are some radical mandates and reforms that are disguised as solutions to the changing climate, Green New Deal comes to mind. Does that sound familiar?

Mr. SHELLENBERGER. I've written about it extensively.

Mr. WEBER. You've written about it extensively.

Mr. SHELLENBERGER. Yes.

Mr. WEBER. It is estimated to cost about $39,000 per household in electricity costs alone. Factor in the health care, transportation, and housing parts of it, and that one single piece of legislation is estimated to cost about $93 trillion total, give or take a few hundred billion. Reckless spending in my opinion is not the answer.

Let's use Germany as a model. They made a decision, as you're probably well aware, to phase out both nuclear and coal plants. They spent €32 billion with a B per year on renewable energy between 2014 and 2018. What do they have to show for it? A mere 40 percent of the electricity supply is now renewables and hardly any, zero decrease in emissions, hardly. Massive spending is not the answer. Radical reform is not the answer. Nuclear, who knew, just might be part of the answer. Would you agree, yes or no?

Mr. SHELLENBERGER. Absolutely.

Mr. WEBER. That's even better than yes. So my question to you is this. What are the major hurdles preventing nuclear from being the cost-competitive solution in the United States? And please don't say Democrats. We're in an open hearing here.

Mr. SHELLENBERGER. Well, the short version is there's a number of factors, but one of the main problems in the United States has been that we have many utilities, and what that means is that we've had many different operators and many different plant designs.

So the economics of nuclear are really simple. The way that costs come down is by standardizing the same design and having the same people build it over and over again. That's the only way we know how to reduce costs, also by increasing the size of the reactor. That's what's worked to reduce costs in France and South Korea, even in some parts of the United States. So that's a major obstacle.

And like I mentioned, it's also been the fear of nuclear, so the way that the antinuclear folks drove up costs was through lawsuits and regulatory ratcheting, which delayed construction and drove up the costs. So this is why I want to warn against—I think there's a lot of wishful thinking that we're going to get some new design that's going to solve these problems, but what really matters is a long-term commitment to building the same kind of reactor over and over again preferably with the same construction managers.

Mr. WEBER. Are you aware that with the argument that the problem is the storage of the waste? That's the major problem here? It's what we do in America. Of course, I'm sure you're watching the ongoing debacle about Yucca Mountain. I'm sure you've been paying attention to that. I did a little research, and there's many types, as you know, of radioactive waste. The United States only has one facility engaged in permanent disposal of nuclear waste, the Waste Isolation Pilot Plant in New Mexico, which permanently stores certain forms of radioactive waste generated by the DOE doing research on production of nuclear weapons. Are you aware of that?

Mr. SHELLENBERGER. Yes.

Mr. WEBER. So we've got to do better that we've got to come to a consensus on how we're going to handle this waste, and then we have the ultimate green energy. Would you agree?

Mr. SHELLENBERGER. I agree. And the only caveat I would add is that I think that the fear of so-called nuclear waste, which is just the used fuel rods, is, again, just a displaced anxiety around nuclear weapons. As an environmentalist, nuclear waste is the major environmental benefit of nuclear power plants—when you go to take an environmental studies class, the first thing you learn is that the perfect environmental production methods store all of the waste at the site of production. Only nuclear does that. Solar panels create 300 times more waste than nuclear. It's all going to go to landfills.

Mr. WEBER. Say that again.

Mr. SHELLENBERGER. Solar panels produce 300 times more waste than nuclear. It's all going to go to landfills. Only nuclear, only nuclear contains all of its own waste product. The nuclear waste has never hurt anybody, never should hurt anybody. It can all fit on a single football field stacked 50 feet high. As an environmentalist, this is the holy grail of energy production.

Mr. WEBER. Thank you for that. And Madam Chair, I yield back.

Chairwoman JOHNSON. Mr. Perlmutter.

Mr. PERLMUTTER. Thanks, Madam Chair. And I was hoping we wouldn't get into kind of a confrontational conversation today and that the narrative would be positive, so let me just start with positives.

So, Dr. Steltzer, thank you very much for your testimony. And everybody, thank you for your testimony. But you talk in terms of stories or narratives, and we have sort of past narratives. What narratives do you see potentially both good and bad going forward? What would you like to see be the narrative?

Dr. STELTZER. What a fantastic question to be asked in a room that has on the wall, "For I dipt into the future, as far as the human eyes could see and saw the vision of the world and all the wonder that could be." I see the wonder all the time. I live in the western U.S. You wouldn't believe how amazing it is where I live, especially when there's snow on the mountain tops. And, to be honest, when there's not snow in the valleys because you get the contrast and the pop of the landscape in different ways and you know what it feels like to be someplace tucked away warm with abundant water available.

The opportunities we have are to include as many voices as we can, to work constructively together and to recognize that our choices should be ones that benefit as many as possible and also focus on reducing harm. One of the concerns I've had in some of what I've heard about nuclear is that we haven't talked yet about where the uranium is mined from. And I live in the part of the country where the uranium is mined from. I know people who have been impacted by past uranium mining, and I live in a watershed where three million gallons of acid mine drainage water came tumbling down.

It is a really weird moment when your river is no longer the color water you're used to water being and instead it's orangebrown, rust. And that was iron. That was an impactful experience for the region.

And so a part of the vision for the future is where and how can we manage to minimize trauma, the trauma that's caused by this feeling of uncontrolled changes, where and how can we have more people involved. So thank you very much. I'm sure somebody else might want to answer that question, too.

Mr. PERLMUTTER. Well, let me just sort of follow up on that. I mean, I think the narrative that I'd like to see is that we recognize we got a problem. And part of the solution may be nuclear. Part of the solution is going to be efficiency. Part of the solution is going to be a whole variety of things, but it does start with a conversation. It does start with you meeting with Chinese scientists at the top of the world, OK? That's how it works. And time is of the essence. I think everybody on this panel agrees to that. Wouldn't you, Mr. Shellenberger, agree time is of the essence?

Mr. SHELLENBERGER. Yes, and I hope I conveyed that urgency in my remarks.

Mr. PERLMUTTER. And it isn't as if nuclear doesn't have some drawbacks because we all have seen Fukushima, and the cost to the Japanese is untold still today. So there are pluses and minuses to all of this stuff.

So, Dr. Murray, I'd like to talk to you for a second. I just saw—and I don't know, these numbers are just phenomenal, but analyzing data from the 1950s through 2019, the world's oceans in 2019 was .075° Celsius higher than 1981 to 2010. And then he says that's 228 sextillion joules worth of energy, which they then say is equal to five atom bombs per second heating to the oceans. So can you talk about that a little bit about what's happening to the oceans and the increased temperature there?

Dr. MURRAY. Yes, Congressman. I believe you're referring to a paper that was just recently published, and they document that, as has been well-known, that 90 percent of the excess heat is stored in the world's oceans. So they've also documented that the world's oceans in 2019 were the warmest in recorded human history and that each of the preceding decades was also the warmest up until that point in time. And this is important because, as the atmosphere warms, so does the ocean.

And we don't have a good handle yet as to the global extent. We need to increase our certainties on what those values are. And then we also need to understand how much more warming and where in the ocean that will actually happen. As the ocean warms, it expands. Warm water is a little bigger than cold water, so the heating alone of the ocean is going to be contributing to a foot or so over the coming 70 or 80 years of sea-level rise, in addition to just the ice melting on land and running into the sea. We also don't understand how much more heat the oceans can handle and what parts of the ocean are doing that. So the atmosphere-ocean linkage is intimate, it's profound, and it's critical to our understanding and predicting the future.

Mr. PERLMUTTER. Thank you very much. Thanks for your testimony. I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Marshall.

Mr. MARSHALL. Thank you, Madam Chair.

My first question is for Mr. Shellenberger. Certainly I believe in an all-of-the-above approach when it comes to domestic energy production. How would you respond to those who believe that advances in renewable energy technologies have eliminated or will eliminate the need for energy and other traditional sources?

Mr. SHELLENBERGER. Thank you for asking that question, and I'll address some of this to Mr. Perlmutter, too, I think around the story. I think we have to understand that energy density of fuel determines the environmental impact, full stop. This is a physical process, so the energy density of wood is half that of coal. The energy density of a quantity of uranium is a million times higher than coal. So to the question of uranium mining, well, first of all, most of it is now in situ, underground. We don't actually dig anything up, but you're having—this amount of uranium or really two glasses' worth of uranium is enough uranium to power my entire life.

So the question is, I mean, do we really need—you know, and this is the issue with renewables. Do you really need renewables if you have nuclear? Well, France did an experiment. It had 75 percent nuclear. It added a bunch of wind. In order to add all of that wind onto the grid, it had to increase the amount of natural gas it burned. It's carbon intensity went up.

So I think we have to just ground ourselves in the fact that energy density of fuel determines environmental impact. Humans gradually move from energy-dilute fuels toward energy-dense fuels——

Mr. MARSHALL. If I could go back to my questions. Do you believe the advances of renewable energy technologies have eliminated or will eliminate the need for energy from other traditional sources?

Mr. SHELLENBERGER. No, and they can't because we can't make sunlight or wind more energy-dense, and we can't make them more reliable. Which is why a solar farm takes 380 times more land than a nuclear plant. It's just not going to change.

Mr. MARSHALL. OK. Next question also for Mr. Shellenberger. If you could comment on suggestions by recent articles that aggressive efforts to pivot to clean energy sources such as outlined by the Green New Deal might dramatically increase energy prices for consumers? You know, as the obstetrician, young couple starting off, that energy bill, the electricity bill was a big chunk of their income. What do you think things like the New Green Deal would do to energy prices for consumers?

Mr. SHELLENBERGER. Yes, what we know is that significant deployment of solar and wind increase electricity prices and increased electricity prices in Germany by 50 percent. They now pay about 50 percent more than their neighbors. We saw that in California. Our electricity prices went up 7 times more than the rest of the United States because of our integration of renewables. There's no mystery as to why. To integrate significantly unreliable electricity onto the grid you have to have 100 percent backup usually from natural gas or some other source of energy.

And of course, as you point out, raising energy prices, like increasing the price of food, is regressive. The people that suffer the most are the poor and the working-class. So anything that increases energy prices is going to be regressive and harmful to working-class and poor people.

Mr. MARSHALL. OK. I stay with you I guess for my last question. See if you would kind of agree with this philosophy. To me, the greatest determinant of the carbon footprint of this world over the next decade or two will be the world economy, that if we have a strong world economy, we can do things like provide infrastructure for natural gas. To your point, in a bad economy, people burn wood, very energy light, versus being able to burn natural gas, which is going to be more efficient and more energy-dense. Do you have any comments on that concept?

Mr. SHELLENBERGER. Well, you're right in the sense that we decarbonize along with economic growth. The idea that we need to have less economic growth in order to decarbonize is not grounded in reality. It's not grounded in historical fact. Obviously is terrible for political economy and it's the reason why climate change legislation, cap-and-trade legislation failed is because people didn't want to increase energy prices. What we saw is that American consumers benefited to $100 billion a year thanks to cheaper natural gas prices, so our emissions from electricity have been going down thanks to a cheap and abundant natural gas as our electricity prices have been going down from cheap natural gas.

The French are not poor. They're the most decarbonized economy, next to Sweden, the most decarbonized economy. They're not poor because they've slashed their emissions and decarbonized their energy sector. Wealth and decarbonization go hand-in-hand.

Mr. MARSHALL. Yes, thank you so much, and I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Tonko.

Mr. TONKO. Thank you, Chairwoman, for holding this hearing, and thank you to all of our witnesses.

Climate science should inform Federal action. Science and research should guide us forward and be the foundation for our action. And, as we know all too well, inaction is incredibly costly. There is a cost to inaction.

So, Dr. McElwee, thank you for your testimony on how lands can be an important climate solution. Can you give us a sense of either the global or U.S. potential of land use to be a net sink of greenhouse gas emissions?

Dr. MCELWEE. Yes, when we talk about land, we talk about land as being both a source and a sink, so we do generate some greenhouse gas emissions from the land sector, and we can be reducing those. But the great advantage is that sink capacity, and that can make up for some of our emissions in other sectors. As I said in my written testimony, it can't make up for everything, but it can help us get to some of these targets that we want to achieve.

So I mentioned, for example, that natural climate solutions can get us a substantial way toward goals of reducing emissions by 2030, very quickly. And what those entail are basically using our natural resources like soil and forests and grasslands and so forth and reducing any emissions that are coming from there and encouraging their sink capacity.

So our report talks about a number of those actions that have a substantial ability to bite into those carbon emissions. And so in our report we lay out things that have on the order of potential 3 gigatons per year going up to 2050, and those include increasing soil carbon sequestration and includes tackling global deforestation, preventing that, land-use conversion of high-carbon lands like wetlands and peatlands. That contribute to the problem. We lose their sink capacity. So if we do things better in terms of conserving natural lands, increasing soil health, improving our agricultural lands, that's going to get us a pretty substantial chunk of carbon emissions. They're not insignificant. And they often come at low cost. That's the bonus.

Mr. TONKO. Thank you. And, Dr. Steltzer, we often hear that the Arctic is a hotspot for climate warming. In fact, in a recent briefing I learned that rapidly rising Arctic air temperatures are thawing soil that has been frozen for millennia. And because of that, the Arctic is undergoing massive landscape-scale change. Do these changes impact the ability for land to sequester carbon?

Dr. STELTZER. The warmer soils lead to microbes in the soil using the carbon that's there. And though the plants are growing more, they can't grow at a rate that pulls enough carbon in to balance what is moving out from the microbes using the carbon that's in the soil.

The other piece of the Arctic story is the part of a lot of land change, and that's when places get drier, they burn, and burned places don't have the vegetation to be the carbon pump that year or the next year. Tundra landscapes can regrow. They take much longer than forests to regrow.

Mr. TONKO. So if we want to make the most out of our agricultural and forest sectors as climate solutions, it seems to me we need to get to work immediately.

Ms. Fransen, the 2019 UNEP Emissions Gap Report, which you were a lead author, describes opportunities to enhance ambition and action on the climate crisis, specifically the contributions of G20 members. It directly addresses the G20 stating G20 members urgently need to step up their commitments on ambitious climate action. What do you project will be the effects of other G20 nations if the United States adopts the ambitious nationally determined contributions in order to meet its long-term strategy?

Ms. FRANSEN. Thank you. Historically, the U.S. has been able to play a constructive role internationally through diplomatic efforts engaging countries like China around making climate-change commitments. So we saw this in the leadup to the Paris Agreement where, through U.S. diplomacy, China came to the table and committed to peak its emissions by 2030. They're now on track to peak in advance of that.

So I think that, as well as many other examples, show that when the U.S. is engaged on this issue as a leader, it can play a strong and constructive role in bringing other countries to the table and getting good rules in place internationally that promote transparency, accountability, robust market mechanisms, and so on to solve this problem.

Mr. TONKO. Thank you. With that, Madam Chair, I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Baird.

Mr. BAIRD. Thank you, Madam Chair. Thank all the witnesses for being here.

You know, it's been a long time since I used the formula to convert centigrade to Fahrenheit, so it was reassuring to me that you take Fahrenheit is equal to centigrade times, what, 9/5 plus 32. Water still boils at 212° Fahrenheit and 100° centigrade, so I thank you for making me review my background a little bit on that.

But, Mr. Shellenberger, earlier this year, I had the privilege of attending the unveiling of Purdue's little small nuclear reactor, and they went all digital. But it would appear to provide the way for big data applications and increased reliability and so on. So in your testimony you say that if nothing changes, China will surpass the U.S. in installed nuclear capacity by 2030 and Russia by 2034.

So here's my question. Could you elaborate on the investments in technologies like that we're developing there at Purdue and help give us an advantage in this global competition, as well as if the U.S. develops advanced reactors or small modular reactors, how much of an international advantage would that give us? And is that the type of technology that is best suited to be exported?

Mr. SHELLENBERGER. Thank you, sir, for that question. What I want to stress about advanced nuclear technologies and nuclear technologies is that they are at risk of becoming orphans without a national nuclear program, without something like a green nuclear deal. And so China and Russia are also developing small modular reactors. They're also developing non-water-cooled reactors, ones that use molten salt or liquid sodium reactors like we've developed.

So when countries make decisions about who to partner with, they're actually choosing countries based on which countries have the most experience building those reactors. As a policymaker, I'm sure you can understand if you're looking to make a big investment with taxpayer funding, you want to go with the tried-and-true management, as well as design.

And so my concern is that these promising new reactor technologies we're developing that we're not really set up at all to be competing with the Chinese and Russians. We need our Head of State selling them to compete with Putin and Xi, who are aggressively selling them. We need to have the right financing for countries. And when they say to us now who would build this plant for us, we don't have an answer. The answer needs to either be Bechtel or some other major construction firm, and right now we sort of say to them, hey, you can pick whoever you want. When you go to Russia or China, they say here's exactly how it will work. Here's the people that will build it. Here's the financing for you to build it.

And, like I mentioned, you know, this is a very special technology. It's a dual-use technology. The U.S. Government has always understood that the United States needed to be leaders on nuclear. And right now I worry that we've engaged in a kind of wishful thinking that somehow some new technological breakthrough will make the difference when in fact our technological breakthroughs just aren't that different from the technological breakthroughs that we're seeing in Russia and China.

Mr. BAIRD. Thank you. I would like to have you add on to that. You know, of the technologies that we have right now and if we could fully develop some more of those, what's the potential for nuclear energy to supply what percentage of our energy needs around the world?

Mr. SHELLENBERGER. I mean, I believe that eventually we will be 100 percent nuclear. It may not be for another 200 years, but it's such a clearly superior energy technology. I think that is eventually what will be. Obviously, you know, France has proven that it can be 75, 80 percent nuclear without any problems. The United States was headed toward 50 percent nuclear. The antinuclear movement succeeded in killing half of all reactors, a little over half, so today we get 20 percent. I think it would be a perfect goal to have to get the United States back up to 50 percent nuclear.

The market right now Russia and China have order books of about $150 billion for new nuclear builds. This is great business. These are big construction projects, high technology, well-paying jobs. I find myself very concerned by the ways in which we're sort of sleepwalking into third place in this global competition.

Mr. BAIRD. Thank you. And I see I'm almost out of time. But, Dr. McElwee, I would like to have you elaborate more at some point, not now, about agriculture because of my background in carbon storage and covered crops and so on. So thank all of you for being here, and I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. McNerney.

Mr. MCNERNEY. Well, I thank the Chair and I thank the witnesses. I appreciate your testimony and your work in the field.

The planet is continuing to warm, and unfortunately, I believe that we're going to blow past 2° centigrade. While we must drastically reduce carbon emissions, I firmly believe we need to explore all the possible tools that we have at our disposal. And that's why I recently introduced the *Atmospheric Climate Intervention Research Act*, which authorizes NOAA (National Oceanic and Atmospheric Administration) to advance research on atmospheric climate intervention modeling and technologies. NOAA is already active in observing and monitoring atmospheric chemistry and dynamics. My bill will help them expand that effort.

Dr. Steltzer, do you believe that we have the capabilities needed to accurately and fully monitor changes in the Arctic and cryosphere, particularly with regard to rapid changes or approaching tipping points? Do we have the ability to understand that yet?

Dr. STELTZER. That's such an interesting question to be asked. Thank you. I mean, I'm a scientist, so I feel like I have to give the science answer, which is that we will never fully understand the complexities of our Earth. And, you know, I apologize if that sounds like then why try, but of course we will always try even if we know that we're trying to solve the biggest puzzle ever. And we will bring everyone to the table.

So I think that where and how we move our understanding of the Arctic forward the fastest is to work collaboratively with other countries that are also working to understand the Arctic because some places will change in different ways than other places. It's a big, big, vast region. We need to understand the land and the sea. And we want to reach out to the people who've long lived there. And we want to understand where and how their knowledge systems contribute to our understanding of what patterns have they seen of change.

A Yupik woman once said to me while we were walking across the tundra—and the Yupik are the native people of the western part of Alaska. She said to me, "When we lose the lakes, we lose the sky." And there is an incredible amount of understanding packed into that that gets the physical, chemical, biological processes change that happen when you lose lakes across the landscape.

Mr. MCNERNEY. Well, how fast are the Arctic and cryosphere changes moving relative to the modeling of those changes? In other words, are the models keeping up with the rate of change?

Dr. STELTZER. I'm not sure. I'd have to get back to on that one. I'd like to get back to you on that one.

Mr. MCNERNEY. OK. This is a question for all of you. Given the complexity of climate system and the risks associated with further human interference, would you agree that additional research is necessary to understand the stratosphere and how the stratosphere is changing? Just answer with a yes or no.

Dr. MURRAY. Yes.

Mr. MCNERNEY. Dr. Steltzer?

Dr. STELTZER. It's not my area of expertise. I don't know.

Mr. SHELLENBERGER. Sorry, I don't know either.

Ms. FRANSEN. Neither do I.

Mr. MCNERNEY. Well, thank you. Well, we were very successful in reducing refrigerant pollution using the Montreal Protocol over the past few decades, and they say that that resulted in the greatest reduction in radiative forcing associated with greenhouse gases of any human efforts to date, so reducing short-lived but strong greenhouse gases strategies is sometimes referred to as fast mitigation and has the potential to help reduce warming in the near term. How adequate are investments in this sort of approach, Dr. McElwee?

Dr. MCELWEE. As I mentioned in my written testimony, one place where we can be doing a better job is on methane, which is one of our shorter-lived greenhouse gases. And we definitely need more research in this area. So one of the things that's been a subject of scientific debate recently is trying to explain some fairly dramatic increases in methane emissions over the last decade or so.

And we are using different tools to do that. We're trying to figure out are these coming from, for example, releases from fossil fuels, so fugitive methane that's coming out of fossil fuel extraction? Is it biogenic sources? And so we need research on all of those areas particularly around how our land sources may be contributing to this increase. This might be one of these climate feedbacks where we're beginning to see, for example, additional methane releases from, say, tropical wetlands that we really need to monitor and understand more carefully.

Mr. MCNERNEY. OK. Thank you. I conveniently ran out of time. I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Murphy.

Mr. MURPHY. Thank you, Madam Chairwoman. Thank you guys for coming out today and sharing your expertise with us. It's very, very important that we hear from you.

I just want to give a few thoughts. I represent a coastal district in eastern North Carolina, and so I understand the importance of addressing this issue. Geological evidence has shown that the climate on this Earth has changed for billions of years. In fact, my home State in North Carolina, Raleigh is smack-dab in the middle of the State, and the geological evidence shows that the coastline was there 100,000 years ago. It happens. I mean, we've been doing this for billions of years.

I'm a surgeon, I'm a scientist, so I don't deny facts. We're dealing with a real issue. But I believe that, you know, God created this Earth. He created it for us to enjoy its resources but also to balance our ability to manage those resources. And it's important that we invest in a large number of alternative technologies, and nuclear hands-down is where we need to go.

My questions then run around the fact that, you know, the U.S. has led the world in decreasing our carbon emissions. You know, it's said that we have to be the world's leader. Well, we are. The problem is that the world's worst actors: China, India, Russia, are actually increasing rather than decreasing their emissions. And so it's not to say that we're not making a difference, but if these bad actors are doing what they're doing, are they nullifying everything that we're doing?

You know, I think an overlooked issue this morning has been one that we need to deal with. It's called mitigation and adaption, which we as humans, that's what we do. And so, you know, a great example, the Netherlands, been there multiple times. They've lived 15 feet underwater for the last 300 years. We need to learn from them. We can't just stick our head in the sand and say that our changes are going to change everything.

And so I think that this Nation needs to look toward innovation rather than running around with our head on fire to actually do what we can to continue to live on this Earth with five and six billion people.

So with that said, just have a couple of questions, first one directed toward Dr. Steltzer if you would. And it's not meant to be an animus question by any means, but if we were able today in the U.S. to decrease our emissions to zero, how much time could we buy? I mean, with what's going on in the Earth and what's happened for billions of years, what are we looking that we could actually buy?

Dr. STELTZER. I don't know that I can give you a number on that, but I'd say that if we did what you just proposed, we would be good neighbors. And one of the pieces of the oral testimony I didn't have time to talk about is that that's one of the visions I have is where and how can the U.S. play a role as a good neighbor, putting forward an example that we want others to follow. And that doesn't mean zero today, zero tomorrow, but that means that we continue to do what we can to decrease our fossil fuel emissions.

And we support the sharing of the technology and expertise that we have with other countries to encourage and support them in doing what they can do.

I think most people want to see—this gets at what Mr. Perlmutter asked me earlier. Most people want to see us working together within a country and across countries and doing what we can to minimize harm to people. And we just need to motivate the spaces and places where we can do that. Thank you.

Mr. MURPHY. I would agree completely. The problem is we have people in this world—China, Russia, India—that don't give a hoot about what we're doing. And so we're fighting that. We're really fighting that. It would be great if, as we're a good neighbor, that they would be good neighbors, too, but they're not.

Final question to Mr. Shellenberger. Can you just give a quick 30-second illustration of fission versus fusion, and wouldn't it be great if we could get to fusion? And when are we going to get there?

Mr. SHELLENBERGER. I mean, honestly, I have an unorthodox view on this, which is that I think fusion is probably inevitable. I don't think it's anytime soon. It could be hundreds of years away. And I don't think that the advantages are all that greater over fission. I mean, fission already—we radically dematerialized, decarbonized with fission. You know, like I said, I don't think it's a technological problem. I think it's more of a consciousness problem, a fear problem, an institutional problem. I still support R&D for fusion. I just don't think it's the holy grail that a lot of other people think it to be.

Mr. MURPHY. All right. Thank you. Thank you, Madam Chair. I yield back.

Dr. MCELWEE. May I comment on the China-India good neighbor question?

Mr. MURPHY. I yield my time.

Chairwoman JOHNSON. Yes, go ahead.

Ms. FRANSEN. Thank you. I just wanted to build on Dr. Stetzer's points by noting that since the dawn of the Industrial Revolution the U.S. has emitted twice the carbon that China has and about six or seven times the amount that India has.

And I would also note that by going to zero emissions rapidly, we can improve health outcomes in the U.S. We can increase U.S. competitiveness through innovation by building technologies for which there is going to be a $23 trillion market around the world. So this is very much in our interest. Thank you.

Chairwoman JOHNSON. Thank you very much. Mr. Crist.

Mr. CRIST. Thank you, Madam Chair. And I want to thank the witnesses for being here today.

As all of you know, my home State of Florida has been ravaged in recent years by outbreaks of harmful algal bloom. Dr. Murray, can you discuss the connection between climate change and increasingly severe outbreaks of blooms such as red tide?

Dr. MURRAY. In general with the increasing population density along the shoreline, an the increasing amount of nutrients that are going into the water and with the warming waters in general, those experts tend to predict that there will be increasing amounts of harmful algal blooms.

Mr. CRIST. Just this past weekend I held a red tide roundtable in my district in St. Petersburg where I brought together scientists, State and local officials, business owners, other stakeholders to discuss ways to tackle this crisis. And one of the things I heard from the panel was that if we could generate more accurate predictions of where and when blooms will occur if we had expanded observation systems. Again, Dr. Murray, can you discuss our current ocean-observing capabilities, how they support algal bloom prediction, and what additional capabilities might be needed?

Dr. MURRAY. Harmful algal blooms by most measures are most impactful on us right along the coastlines. And the coastlines from the water perspective are surprisingly hard to monitor and set up long observation systems in. We have a fair bit of stuff that is a little further offshore, but looking at how the ocean currents are moving up and down the coasts in that critical interface zone is surprisingly difficult. There is some land-based techniques with various imaging systems looking out to sea that are very helpful on understanding ocean circulation, air-sea interactions, but again, we need more of those.

A large issue, a potential answer to your question as well as to some of the ones from Congressman Murphy regarding mitigation-type things along the coastline, you know, in terms of the physical impacts of sea-level rise but in terms of the chemical impacts of nutrients going in, we need to do a better job in our sewage treatment plants inputs, our local infrastructure, which are all going to be impacted by rising sea level.

I live in a coastal community in Massachusetts, so I'm very aware of what happens when sea level is rising, temperatures are warming, and there's a whole domino effect of what's going on. We can pick on harmful algal blooms; we can pick on sea-level rise. All these things are all related. Coastal ecosystems is storage of blue carbon is helping us mitigate inputs of pollutants and nutrients. All these things are related, chemical, biological, and physical.

Mr. CRIST. Thank you. Another thing I heard at the roundtable is that translating science from the observing arena to the operations arena can be a challenge, and the critical information can get lost in the translation. How could we better move scientific data from the research and observation side to the applied side so that local officials and general public can best be informed as to when and where algal blooms will occur?

Dr. MURRAY. There I would speak to the importance of making data readily available and readily available by the decisionmakers of the communities, the municipalities along the shoreline. So what the predictive models are on sea-level rise: Where, how fast, what type, bringing in wave energy, and so on, but having that data available and available in a way that people can use, so NOAA, the U.S. Geological Survey, NASA (National Aeronautics and Space Administration). When I was advising with OSTP, we worked very hard on making sure that those agencies were communicating with each other and coming up with consistent data sets and visualizations that the local city owners and city managers and so on could work on. But I would really focus on the data aspect.

Mr. CRIST. The Union of Concerned Scientists recently released a report on extreme heat across the U.S. According to that report, the United States can expect a number of days with the heat index above 105 degrees to quadruple by the midcentury and increase eightfold by the end of the century. For example, in my district of Pinellas County, Florida, has a historical average of 1 day per year above 105 degrees. According to this report, that average is expected to increase to 77 days by midcentury and 123 days by the end of the century. That's over 1/3 of the year.

Dr. McElwee, can you describe the potential impacts that a sharp increase in the number of extreme heat days will have on the economy, particularly as it relates to outdoor workers and tourism in places like Florida?

Dr. MCELWEE. Certainly. We know that extreme heat events, as you say, are projected to increase. The evidence is very clear on that. And so with that comes a number of health impacts. So obviously there's heat stress on people who have to work outside. Mortality in general goes up when we're outside, and so we're concerned about all of those issues.

But let me also point out that what we're seeing, for example, in Australia right now with the extensive bushfires, they have had similar days. In fact, it's been over 40° Celsius in some parts of Australia for an extended period. And those create the conditions for wildfires to start and extend. And so we have multiple things that are related to these extreme heat events also related to agriculture. Extreme heat can have an impact on our crop yields and so forth. So there's intersecting issues, but you're absolutely right. This is one area where the science is extremely clear that we are very confident that these are associated with anthropogenic climate change.

Mr. CRIST. OK. Thank you very much.

Chairwoman JOHNSON. Thank you. Mr. Babin.

Mr. BABIN. Thank you, Madam Chair. And I want to thank the witnesses for being here as well. Fascinating stuff.

And it looks to me like from what I hear, and I've read a lot of your stuff here, Mr. Shellenberger, that nuclear may be the only way that we can get off of the dependence on fossil fuels or, because obviously the renewables don't seem to cut the mustard.

But the U.S. has always been the leader in nuclear power construction in the past for safe and reliable nuclear plants. I noticed that China and Russia are leading in the number of plant construction around the world, and many other nations are kind of saddling up to them and dependence on these two nations when we build a better plant. So if that's one of the problems, the price tag of clean energy is so high right now, at what point do you see clean energy becoming cheaper and more viable? And is it going to be a reversal of the trend that we're seeing on nuclear here in the United States?

Mr. SHELLENBERGER. And when you say clean energy, are you referring, sir, to nuclear in specific or are you saying all low-carbon energies, including renewables?

Mr. BABIN. I would say well, I was talking specifically about the nuclear end of it because you had had so much in your documentation here that I was reading about. So I would say that. You can throw in the other ones, too. I'd like to hear what you have to say.

Mr. SHELLENBERGER. Sure. I'll give you one study we did where we calculated that. Had Germany spent the 580 billion it's estimated to spend on renewables by 2025, had it spent it on nuclear, it would already be at 100 percent zero emissions electricity, and it would have completely decarbonized its transportation supply, a similar case in California, so it's very easy to do those calculations.

The challenge for nuclear is that it requires national level commitment from the top. It really requires the President to be a leader on it. It requires significant congressional leadership. I would note that, for example, Russia also has abundant natural gas supplies, and what it's choosing to do is replace its use of natural gas domestically with nuclear power plants and export its natural gas abroad. That seems like a great recipe for energy dominance. It seems like that would be the heart of an energy-dominant strategy internationally and one that the United States would do well to follow. But again, it really requires this kind of long-term national commitment.

Mr. BABIN. Absolutely. We hear a lot of extreme rhetoric. In fact, some of us Republicans, you know, the claims that we're climate-change deniers, and nothing could be further from the truth. I've got a science background myself. I'm a dentist with a biology degree and studies in science. And I can tell you that we know that the climate is changing. There's no question about it. No district has been hit any harder than mine down in southeast Texas by hurricanes and floods, so we know things are happening.

But we also hear some of this extreme rhetoric. Civilization will end without radical action. Children are suffering from eco-anxiety and depression. And I read where no credible scientific body has ever claimed that climate change threatens the collapse of our civilization or the extinction of Homo sapiens. And yet we hear politicians and the media are making these claims. I'd like to hear your opinion and tell me what you're thinking about that.

Mr. SHELLENBERGER. Thank you for asking that question. And it's very troubling, the rise of this rhetoric. It's obviously been around for several decades, but it's become much more acute in recent years. What we've done is we went and interviewed the scientists who activists told us they were relying on for those catastrophist claims. Four of the scientists we interviewed all claimed that they were misquoted. One of them told us that it was based on his best estimation that the world could not sustain half of its human population at a 4 degree temperature rise. We asked him what that was based on, and he said it was just him speculating.

In fact, there are studies by the Food and Agricultural Organization, and the major factors that determine how much food we will grow—because the only way you can really come up with collapse-of-civilization scenarios is with a collapse of food supply—that the major studies show what determines food output in the future is the same thing that's determinant in the past, which is whether poor countries have access to fertilizer, irrigation, and tractors. And so if we're really concerned about sub-Saharan Africa, for example, or South Asia where people are much more vulnerable and dependent on nature, on less resilient, then we should be helping them to industrialize agriculture, to urbanize, to gain access to factories. That's already starting to happen in Ethiopia. It should happen on the rest of the continent.

So what bothers me is the way that this apocalyptic discourse is used to justify denying poor countries cheap baseload electricity not just from fossil fuels but we've also seen this effort to stop poor countries from getting large hydroelectric dams and large nuclear power plants.

So what I always say to my colleagues as if you're so worried about denial, then I think you should stop trying to deny poor countries the cheap, reliable sources of electricity and energy that they need in order to survive a hotter world.

Mr. BABIN. Absolutely. And my time is expired. And I for one am very happy that we had the availability of fracking and the increased production of natural gas in my home State, which has led to energy independence for the United States and the lowering of emissions and been very, very significant. So thank you, and I yield back.

Mr. SHELLENBERGER. Thank you, sir.

Chairwoman JOHNSON. Thank you. Mr. Lamb.

Mr. LAMB. Thank you, Madam Chairwoman. And I want to thank all the witnesses for coming to be with us here today.

Mr. Shellenberger, you're getting a lot of attention, and I have to say I'm very happy about that. The district that I represent in western Pennsylvania is the home of the original Shippingport nuclear power plant, the first civilian reactor built in the United States as part of the same program that led us to build reactors for our oceangoing vessels in the Navy.

And in my office I have a picture of President Eisenhower waving this—well, it was actually a fake wand. He did a little press event to show the start of the construction of that, but he was somewhere else at the time, and he waved a wand, and the first backhoe or whatever started moving dirt at Shippingport. So we have a plant there now, Beaver Valley, which is at risk of being closed.

You know, nuclear, in a lot of ways the lack of support for it at our Federal Government shows a lot of the things that are wrong with Washington in that it has no natural friend on the side of those who consider themselves the environmental left. But frankly, it also has been kind of unfairly targeted and undermined by certain fossil fuel lobbies. And in our own State, natural gas has become so cheap that it makes it difficult for nuclear to compete without any sort of support. And people make it seem like the request for support is kind of an unfair thumb on the scale, which couldn't be any further from the truth. I mean, nuclear just does something that natural gas does not do, which is produce energy without carbon. And it does not get compensated for it at all.

And so, you know, we're left with the support for nuclear being among scientists, you know, people who aren't either on really the right or left but simply the side of the facts, and so I thank you for presenting those so well today.

In addition to the scientific facts, I just want to point out some social facts about nuclear power, which is that it employs tens of thousands of veterans and union electricians and union construction workers in my State already. So we're not talking about the future potential of renewable energy, for example, to create as many jobs as it may erase. We're talking about people who are already working and earning good middle-class salaries and raising their families based on this technology, which was invented by our government for an idealistic and environmental purpose. And I know you know that, but I just want to make sure that the jobs angle is included.

And to my friend Mr. Brooks who was asking about what do we do about India, China, Russia? At least with respect to India, one of the things we do is sell them nuclear energy. And you started to point that out today, but I think on a grander scale I've been told that we're looking at about a trillion-dollar export market probably, maybe more, that will go to someone. So this is $1 trillion worth not only of the construction workers who go to build the plant and the designers but the people in my State who make all the parts.

There's a manufacturer in my State who does about half its business for civilian nuclear reactors and half for the Navy. And when I visited, they told me this hilarious example where when the Chinese come to buy replacement parts for their AP1000s that they have, they literally have to put sheets and blankets over the Navy equipment that they're making in the same warehouse so they don't steal our naval technologies. So this really exists that we have a manufacturing economy related to this.

And if we want to preserve those jobs and increase them by selling this stuff domestically and overseas, you've talked about the President being a salesman. I think that works for the overseas market, but for the domestic market, any ideas in the minute and a half I have remaining on what we would actually do to make it economically feasible again? Is it purely deregulatory? And if so, you know, what are a couple of the most important things we can do? Go ahead.

Mr. SHELLENBERGER. I mean, I think the most important thing is a national Green Nuclear Deal so that this is not just advocated by people that happen to have a lot of nuclear in their States or districts. Exelon, which is one of the biggest operators of nuclear plants in the United States, is seeking some sort of subsidy. My view is that any subsidy for nuclear should be in the context of a nuclear growth strategy. Right now, the official strategy of the U.S. nuclear industry is of managed decline. I think that's unacceptable. I don't think it's any taxpayer interest to subsidize an industry that is committed to decline. We need to have a growth strategy.

You're absolutely right. I mean, for me, my view is that the world will go to nuclear after we exhaust every other option, after we try everything else and we discover it doesn't work when clearly we have this amazing technical fix in our hands. And it's one that we must take responsibility over because of the dual use of the technology.

Mr. LAMB. So maybe to cut it short, the government would have to show commitment beyond just changing a few rules but purchase agreements, for example, and things that show that the money will really be there for a long term and the market will exist?

Mr. SHELLENBERGER. Yes, I mean Senator Lamar Alexander for decades had advocated a significant scaleup of nuclear plants. It was basically the right plan. I think everything else is basically wishful thinking unless you're in the place of any really concrete proposals to build nuclear plants.

Mr. LAMB. Thank you. Madam Chair, I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Gonzalez?

Mr. GONZALEZ. Thank you, Madam Chair. And thank you to our panel. First, I'd like to ask unanimous consent to submit the following article titled "Meet Vaclav Smil, the Man Who Has Quietly Shaped How the World Thinks About Energy" in *Science Magazine*. I ask unanimous consent to submit for the record.

Chairwoman JOHNSON. Without objection.

Mr. GONZALEZ. Thank you. So one of the things that we've talked a lot about in this Committee is the issue of climate change. And I think we've actually made progress, sort of this bizarro world where in here I feel like we make progress and they get on Twitter and, God forbid, it's something completely different.

So I want to start first by talking about sort of the transitions. And one of the reasons I like this article is Professor Smil basically goes through and talks about the different transitions from energy sources from wood to fossil fuels, first coal, then oil and natural gas that took over a century. And basically the science is pretty clear that the next transition if we go to full-scale renewables will be very slow. And so these projections, some in the Green New Deal and whatnot, that we can somehow solve this with wind, solar, and battery is fanciful.

And so that's why I've been very excited to hear Ranking Member Lucas' comments on the need to increase basic research and discover the answer to this question because I don't personally believe that it exists with the exception of potentially nuclear. And I know, Mr. Shellenberger, we probably agree on that.

And so I want to start with you. In your testimony I think you make a strong argument in favor of growing our nuclear capacity both at home and abroad, and I certainly agree with you. We need to do more not only to expand our capacity but make it more affordable. Now, as I understand it, nuclear reactors are currently only custom-built, which generate significant costs. How important is the R&D component from an investment standpoint to promote advanced nuclear reactors?

Mr. SHELLENBERGER. I think it's a small but exaggerated part. I have a minority view of this within the pro-nuclear community. I think there's a fetishization of new designs and of that particular phase of the process. Basically, if you look even at solar panels, which have experienced a significant decline in cost, 90 percent decline in cost, it wasn't a breakthrough with a different design. It was actually the same boring old silicon solar panel that they just mass manufactured in big factories in China. And so your point about scale is really, really important. What brings down the price is being able to do the same. It's just factory-type production or mass manufacturing that brings down prices.

Mr. GONZALEZ. And how does the U.S. currently set from a competitive standpoint relative to other nations in developing the technology?

Mr. SHELLENBERGER. As far as I can tell, we don't have a significant advantage in terms of new smaller reactors or novel designs that use a different coolant than water. The Russians and the Chinese are all pursuing that, the Koreans are certainly pursuing it. The Canadians are getting into it. Again, I just think there's just way too much emphasis on design type because I think there's some idea that we're going to have some kind of a breakthrough in design. But that's just not consistent with any physical understanding of the technology or the history.

Mr. GONZALEZ. OK. So what would be the most helpful in terms of increasing our competitiveness?

Mr. SHELLENBERGER. We need to be building significant amounts of nuclear power plants at home. There's no alternative to it, so if you're Nigeria and you're considering who to go with, and the Chinese and the Russians and the Americans come and the Chinese and the Russians are like, yes, we're building, you know, 10 reactors in the next 10 years, and the Chinese are like we're building 20, and the United States is like, well, we were building four but then we canceled two of them and we're hoping to get the two done and maybe we'll build some other kinds but we're not really sure, and, by the way, we don't really know who you could work with in the United States, but good luck. I mean, that's just not a competitive offering.

Mr. GONZALEZ. Right. No, I certainly share that opinion. And with that, I yield back. Thank you.

Chairwoman JOHNSON. Thank you very much. Mr. Beyer.

Mr. BEYER. Thank you, Madam Chair. Thank you all very much for being here with us. You've made the really good case, and IPCC continues to year after year about the need for very deep reductions in future emissions, but I also keep reading again and again that we're not going to be able to do this without negative net emissions, that we have so much that we've already put into the atmosphere.

I was the lead on the *SEA FUEL Act*, which got included in the national defense authorization, to direct the Department of Defense and Homeland Security to pioneer products from seawater. And then Suzanne Bonamici has just introduced a bill this week on the *Blue Carbon for Our Planet Act*, which really pumps up Federal research for the blue carbon systems.

So, Dr. Murray, you're Woods Hole I guess. Can you talk and elaborate on the need for negative emissions technologies and even specifically thinking about underserved communities or economic justice communities and the hard-to-decarbonize industries like cement, for example?

Dr. MURRAY. To be honest, sir, I'm not an expert in those matters that you raised regarding that. I can speak to you about some of the blue economy measures, which are, you know, very, very strong, as you just mentioned with your colleagues, and that sort of thing, which I heartily support because we're going to need those to be part of any equation to get us to decreasing emissions, decreasing down to negative emissions, and so on. But the specifics of cement and such matters like that I'm unqualified to answer.

Mr. BEYER. Dr. McElwee is looking more confident at the moment.

Dr. MCELWEE. I'm happy to speak a little bit to negative emissions technologies. I mean, we have one right now, and it's plant, vegetation, and trees. I mean, they do an excellent job of doing a lot of the carbon dioxide removal that we potentially need. The problem is to scale them up to the amount of land that we would need to make a huge dent would then introduce competition with food production and so forth. So that's why we need potentially other technologies.

And so Representative Gonzalez just a few minutes ago was saying where do we need basic research, and this would be an area. So carbon capture and storage, either direct air carbon capture or bioenergy carbon capture and storage are included in model pathways to reach 1.5 degrees. It is nearly impossible to limit our warming to 1.5 degrees without some of these negative emissions technologies. The problem is the research is not keeping up with our need for them.

Mr. BEYER. That's interesting. And, Ms. Fransen, we have a variety of carbon pricing bills floating around. Chris Van Hollen and I have one. Ted Deutch, he had another using the economic dividend. John Larson has one that funds infrastructure. Can you talk about how carbon pricing—how important it is and how valuable it might be to use market forces to move this?

Ms. FRANSEN. Absolutely. And I'd also like to echo what Dr. McElwee said about the need for negative emissions technologies and carbon dioxide removal. WRI is actually doing a significant amount of research into technology and natural climate solutions that can generate negative emissions, and we'd be happy to address specific questions or follow up on that.

I understand that Congress last year passed $60 million in R&D for carbon dioxide removal, which is a great start. And our research indicates we need to scale that up to around $325 million. So there's a great opportunity there.

Onto carbon pricing. Carbon pricing is indeed a very useful tool to help reduce emissions. It's not a silver bullet. It's got pros and cons, like many other policy instruments. On the upside, what carbon pricing does is change the relative cost of high-carbon and low-carbon goods. It provides incentives for businesses and consumers to shift to existing low-carbon technology.

In terms of limitations, carbon pricing alone cannot overcome other market barriers that limit the uptake of clean technology such as high upfront costs, mismatches between landlord-tenant problems, things of this nature. And a carbon price alone is not likely to provide adequate incentives for investment in technologies that are still a bit higher on the cost curve. So it can serve as a very useful part of a comprehensive policy portfolio to drive down emissions. My colleagues at WRI also do a significant amount of research in this area and would be happy to follow up.

Mr. BEYER. Thank you very much. Dr. Steltzer, I love your Twitter handle, Heidi Mountains, very cool. So you do all this work on mountain slopes and the like. One of the things I haven't heard much today is the impact of eating animal products on climate change. There is a fascinating documentary out there right now called Game Changers that talks about something like 80 percent of our agricultural land in the U.S. is used to grow products for our meat production.

So my time is up, but the throwaway question is, why doesn't the environmental community talk more about that as a solution? I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. McAdams.

Mr. MCADAMS. Thank you, Madam Chair and Ranking Member Lucas and our witnesses for convening here today to talk about recent climate reports and how we can combat this massive threat.

I want to just highlight some recent news, and that is the report from NASA and NOAA that showed that global average surface temperatures last year were nearly 1° Celsius higher than the average from 1951 to 1980, making last year the second-hottest year on record and the decade the hottest decade on record. So I don't think there's any question that we need to take more actionable steps to prevent further climate change.

However, there are certainly a number of ideas about how to address climate change and to build more resilient communities and infrastructure to brace for it. And we've heard many of those ideas from our witnesses and from Members, both Republican and Democrat today.

Last year, the Utah State legislature, my home State, commissioned the Kem C. Gardner Policy Institute at the University of Utah to produce a changing climate roadmap for my home State of Utah to better play its part in addressing climate change. And some of the recommendations that came forward from this report include: One, reducing carbon emissions produced in the State; two, creating an air quality and climate change solutions laboratory; three, implementing large electric vehicle networks throughout the State; four, developing economic transition plans to rural communities across our State.

Additionally, over 20 cities and towns in Utah—there was a recent story in the *Salt Lake Tribune*. Over 20 cities and towns and three counties in my State have committed to getting to zero carbon emissions. So I would like to point out that we are trying to play our part in my State.

So my question for our witnesses, for any of you, is how can the Federal Government both address the need for better climate policy and support our States and our local governments that are already doing this work?

Dr. STELTZER. Hi, neighbor. Colorado, Utah. Thank you. I really appreciate what you all shared. I feel like we don't always know what's happening on the other side of a State border even though we may travel and go to those places. So I expect you've been to Colorado, and I've been to——

Mr. MCADAMS. Yes. Yes.

Dr. STELTZER [continuing]. Utah plenty, and I know how great a State Utah is.

Mr. MCADAMS. The skiing is actually better on our side.

Dr. STELTZER. I have heard that, but nobody's invited me to those mountains yet, and I haven't done any research there. When I come to Utah, I go to the desert country, and what I think about that we could do to help make that work better is to support the connection between people across county lines and State lines for air and watershed wide.

So the water from Colorado makes its way to Utah. You all have some of your own water, too, that falls on your mountains, but the southern part of your State depends on the water from my State. The air that comes into my State comes from your State and across from the west from the Pacific and across, and it brings the water from the ocean.

So where and how do we make those interstate connections? Where and how does our Federal Government help to facilitate those opportunities because of that interconnection between the air and the water? And when we have those conversations, the planning can be with the resilience-mindedness.

And one of the things that I want to highlight about resilience-mindedness because you brought up resilience is it's always about dispersed and diverse. So on a mountain meadow in Colorado the way that from year to year in variable climate cycles, that meadow always provides for the ranching that happens on a lot of these mountain hill slopes is because there are so many different species. And the grasses are really pretty incredible. The different grass species are pretty incredible for what they can do.

And as we focused a lot of conversation today on one energy system, nuclear, I want to put forward a reminder that resilience is dispersed and diverse. And so it's not saying that nuclear can't be a part of the puzzle, but let's make sure we have lots of puzzle pieces at play.

Mr. MCADAMS. Thank you. And I'll leave more time for the remaining people who have questions, but the question was asked earlier, what do we gain if the United States went to zero emissions immediately. And one thing that I would point out in our States we have cleaner, better water, more water, cleaner air. And in this conversation about the global impacts of climate change and how can a small State like Utah have an impact on what's happening around the world, we can have an impact on what's happening in our backyard and make our lives healthier and better for the people who live in our great States. Go ahead.

Ms. FRANSEN. Thank you. It was great hearing about all the things that Utah and cities in Utah are doing. Congratulations. It's fantastic. I think a couple of things. There are a growing number of U.S. States and cities that are being very active on this issue, which is wonderful. They can drive significant emissions reductions. But we know, and as you indicated, they can't do it alone. They can't get us to where we need to go alone, which is to very significant emissions cuts by 2030 and eventually down to net zero.

In terms of what the Federal Government can do to support those efforts, there are a number of things. I would harken back to our earlier conversation about carbon pricing as part of an overall package. That could generate significant incentives to support those efforts. Certainly Federal incentives and regulations to go to zero carbon electricity quickly not only in Utah but everywhere to help incentivize and support the electrification and decarbonization of end uses, providing support to States on building codes, going forward with efficiency standards, those are all things that could be part of this package and support State and local efforts. Thank you.

Mr. MCADAMS. Thank you for those comments. I see my time is expired, and so I yield back.

Mr. BEYER [presiding]. The Chair recognizes the gentleman from Illinois, Mr. Casten.

Mr. CASTEN. Thank you, Mr. Chair. Thank you to all the witnesses for coming.

I want to just start by level-setting a little bit because this won't be news to the folks on the panel, but sometimes the folks watching I think don't follow stuff as much as they should.

Homo sapiens have been around for about 300,000 years, I think culture about 100,000. Fifty percent of all the CO_2 we have ever emitted as a species is since Back to the Future came out in 1985. Dr. Steltzer, as you mentioned, we've got all these positive feedback loops from lowering albedo effect of melting sea ice to accelerating methane release from permafrost and these massively nonlinear shifts, and yet we remain bedeviled by the fact that we have voices that either suggest that this is a step function, all we got to do is just grow crops in Canada, or that this is linear, that it's just, oh, you know, it's slowly changing, or worse, that we can just deny the whole thing is even real. And we struggle on this side of the room with the fact that what is scientifically necessary is so far beyond what is politically possible. And that is a path to suicide.

And so, you know, I think, number one, I'd like to ask us all to please give as much respect to people who would deny the science or deny the urgency of the science with as much respect as we treat people who deny gravity. They've earned it.

Number two, we cannot let the recognition of the urgency allow us to deny the complexity. And I get nervous that when we politicize this we have one side saying it ain't urgent, we have the other side saying it's simple. Both of those are paths to suicide. And so I want to ask a science question and a policy question if I could.

Dr. Murray, I want to start with you. For us to not have to spend the rest of our time on this planet dealing with environmental justice, we have to get back to 1985 CO_2 levels because the sea levels are rising, the oceans are acidifying, heat islands in the cities are growing. That means something like 320 parts per million in the atmosphere. We're at 100 above that right now. Given, as you've described, the oceans play this buffering effect of absorbing CO_2 as it puts into the atmosphere, before factoring in the account that the oceans are going to burp about as we drop, how far do we have to drop atmospheric CO_2 levels to get to the point where we will equilibrate at something like 320?

Dr. MURRAY. I'm going to get back to you on that. That's a very specific question that I don't have the numbers right on hand to answer. It's very clear that rapidly gets into negative emission scenarios that we were talking about earlier and to get the number back.

The other factor involved here is the long residence time of carbon dioxide in the atmosphere has a buffering capacity on the order of like 100 years or 200 years or so. So even if we go to zero now, even if we take 40 years, 50 years if the technology was invented today to start getting to significant negative emission scenarios, we're still going to need to adapt, to mitigate, to do many of these things we're talking about under any scenario.

Mr. CASTEN. Well, I'd appreciate it. The number, it was recently estimated to me, and I'd like to confirm this, that the number is around 280. And if taking 100 parts per million is roughly 400 billion tons of CO_2 if in fact that's more like 280, that's 600 billion tons. I don't know if that's right, but I'd welcome if you could follow up afterwards with some estimate of what you think that number is.

Dr. MURRAY. Yes, we will follow up with that. That scale seems about right to me, but we will get that specific answer for you, sir.

Mr. CASTEN. OK. My policy question is for Ms. Fransen. There is an extremely disingenuous argument going on about can we afford to reduce CO_2. It's dumb, it's irresponsible. And, oh, by the way, zero marginal cost energy is cheaper. I don't care what anybody tells you. I've spent 20 years in the energy industry. Deploying zero cost energy actually lowers the cost of energy. But it takes capital.

The conservative estimates the amount we spend subsidizing the oil, the fossil fuel sector in this world is about $20 billion a year. The International Monetary Fund has estimated that the indirect and direct subsidies get close to $600 billion a year, which is roughly our defense budget, round numbers. Total U.S. energy spend is about $1 trillion a year. Is it your view that the fossil fuel industry would be economically competitive against clean energy in the absence of those subsidies?

Ms. FRANSEN. No, it is not. You're absolutely right that zero carbon energy is now cheaper than existing coal, new zero carbon energy is now cheaper than existing coal in many locations. Those costs are coming down very quickly. And certainly once you factor in the external costs of greenhouse gas emissions and other sources of air pollution and damages that come from fossil fuels in the form of health costs, I could go on, natural disasters that are exacerbated by climate change, et cetera; the economic case for moving to zero carbon energy is extremely strong. Thank you.

Mr. CASTEN. Thanks. I'm out of time, but I just want to leave the question to all of you. With $600 billion a year of subsidies, we spend a lot of time talking about what incentives we can put in place for clean energy. It's politically easier to pass incentives than it is to remove barriers. And if any of you have thoughts you'd like to submit for the record about what barriers we could reduce, I would appreciate it. Thank you, and yield back.

Mr. BEYER. The Chair recognizes the gentlelady from Texas, Congresswoman Fletcher.

Mrs. FLETCHER. Thank you very much, Mr. Chairman. And thank you to the panel for being here this morning. I've really appreciated your insights and your comments this morning.

And I want to follow up on a couple of things that we've heard today. While I, too, would like to make the observation that I think there is more agreement than disagreement on climate change and the need to do something. And it seems to me from where I come from that the question is really how and what do we do. And we need guidance and we need help from the scientific community in helping us prioritize.

I represent the energy capital of the world. I am from Houston. We believe in climate change. We know it's real. We know it's happening, and we want to be part of the solution. That is the consistent message from my constituents, including those who are in the energy business. And I think it's really important that, as we think about solutions we bring everybody to the table, especially the people who have expertise in delivering energy now because that is what we all want to see. We want to see this planet continue for our children and our grandchildren. And we want to make sure that we are part of the solution, not part of the problem.

So with that in mind, there are a couple of things that you all have touched on in terms of technology, and I think that's a place of common ground across the political spectrum. I think this is a place where actually hearing about sort of political difficulties, there's a lot of consensus. And there are two issues that have come up today.

And, Dr. McElwee, I think you were talking a little bit about direct air capture and basic research, and that is certainly an area, as well as CCUS (carbon capture, utilization, and storage) is another place where folks in my community are very interested in investing. When we talk about the basic research we need, there's sort of a concept, but where would you start in terms of doing that research, and what do you see as kind of the science we need to be doing and we need to be encouraging from a policy level enabling, whether it's through the Office of Science or other places to bring that project faster?

Dr. MCELWEE. Let me say first most of my experience with negative emissions technologies is around the land sector as opposed to direct air capture, but they're both very promising, right, so no doubt that we need to move in this direction. I mean, one of the barriers is of course that there is no penalty for emitting carbon, right? And so until we figure out how to internalize that externality, it becomes very hard for the private sector, for example, to invest in some of these very large-scale things that we're going to need. So it's going to need to be a partnership of multiple things where we can bring industry folks on board, but we give them the incentive to do that through, say, carbon pricing or something else.

Certainly we need more partnerships with our universities. There are some really interesting things, for example, at Rice University right now looking at the land sector in terms of getting more money to our ranchers out in east Texas who are doing a great job of conserving soil carbon and improving vegetation on their lands. That actually helps with flooding as well, right? So all of these systems are connected. So if we're worried about resilience downstream and in urban areas, those sorts of projects are what we need to be looking at as well. So it's not always sort of fancy shiny new technology, but it's doing things better that we know we can do.

Mrs. FLETCHER. Thank you for that. And I am familiar with some of the suggestions coming out of the SSPEED (Severe Storm Prediction, Education, & Evacuation from Disasters) Center and other folks at Rice who are working on some of these ideas where there really is a connection. And I think that that's what many of us who are laypeople, not scientists, are looking for.

And so I think you also mentioned in your testimony—and I'd love to hear with the time I have left from each of you—Dr. McElwee, you said in your written testimony one of the findings of work there are a lot of actions we can take now. And so I think if each of you wanted to just tackle that. What do you think is sort of the first thing or a thing that we could do now that would be useful for folks to understand kind of your—I don't want to say your top priority but just one of the many things that's right in front of us, that would be helpful to get your perspectives. Dr. Murray?

Dr. MURRAY. So I'll answer that question also by drawing attention to your—an agreement, your point about there's more agreement than disagreement. And I just want to draw everybody's attention to the memorandum for the heads of executive departments and agencies from OSTP from the current Administration, the current Administration. And they talk about many things in the science priorities for the coming Fiscal Year 2021. But one of the sections is American energy and environmental leadership, something we've all been talking about here today. And they identify three areas of interest. One is energy, which we've certainly talked about a lot here today. The other one is oceans, OK, and it's all oceanographic. I've just got to point that out. But they also talk about prioritizing new and emerging technologies, they talk about batteries, they talk about things like that.

But then the third thing is Earth system predictability, and that's Earth systems, so not just oceans but land, everywhere. And they're talking about prioritizing R&D to quantify different timescales, different geographic areas. They talk about artificial intelligence, adaptive observing systems. These are areas that I think throughout our technological sectors, throughout academia, throughout our national labs are bipartisan, but more agreement than disagreement. So those are the sorts of things that I would be, if I were in your shoes, really looking to capitalize on, many of them that are in this OSTP memo and some of these other things through the years, different Administrations, different Congresses.

Mrs. FLETCHER. Terrific. Thank you so much. And I have actually gone over my 5 minutes. But for the rest of you, if you want to submit a response for the record, I think I can anticipate some of them, but really appreciate hearing from all of you this morning. It's been incredibly helpful. Thank you. And I yield back.

Mr. BEYER. The Chair recognizes the gentlelady from Virginia——

Ms. WEXTON. The great Commonwealth of Virginia.

Mr. BEYER. Loudoun County, Virginia, Ms. Wexton.

Ms. WEXTON. Thank you, Mr. Chairman, and thank you to all the witnesses for coming and sharing your knowledge with us today.

Just outside of my district in northern Virginia is the Smithsonian's Conservation Biology Institute, and they have done absolutely incredible work in conservation and biodiversity. They have brought species that were nearing extinction back from the brink, and they're conducting groundbreaking research on how ecosystems are impacted by climate change and also helping to advise on sustainable development.

Dr. McElwee, in your testimony, you talked about sustainable land use and how that management is an important part of helping us adapt to climate change and the impacts that we're feeling from that. Can you explain a little bit? Are there economic benefits to it as well, and can you explain some of those?

Dr. MCELWEE. Yes, yes. The Smithsonian center in your district is fantastic, and you're really lucky to have it. One of the things I think we haven't emphasized enough here today are the interconnections with biodiversity. So many of the climate impacts that we're already seeing are about species ranges changing and species having to do different things. So we want to make sure we connect that back to talking about impacts because they're crucially important.

In terms of sustainable land management, one of the great things about a lot of our improved land practices ranging from cover crops to no-till and so forth is they're fairly low cost or they might have a small upfront cost but then the payback comes in year 2 and 3 and 4 and so forth. And so the economic benefits can be considerable.

But again, we need to have a balance of incentives to make that happen. So right now, for example, our farmers and ranchers that are doing a better job of conserving carbon on their lands either in soils or vegetation, they don't get rewards for that. There's essentially the benefit for their own productivity, but on top of that all the benefits they're giving to the rest of us in terms of conserving carbon they're not getting economic benefits for. So things like carbon pricing, maybe incentives and subsidies around soil conservation and vegetation conservation, that would make it even more economically profitable to do those sustainable land management practices.

Ms. WEXTON. And related to that, in Virginia we're a part of the Chesapeake Bay Watershed Agreement, and we're very fortunate because we have buy-in from the States, localities. You know, everybody in the region understands the importance of this unique resource that we have. But other areas are not so fortunate and don't have necessarily the same resources or same buy-in. So would you say that those tools about incentivizing good behavior and incentivizing these sorts of agreements also would apply in cases like those?

Dr. MCELWEE. Yes, absolutely. If you look at the States that have the highest percentage of agricultural lands under cover crops, it is precisely Virginia's and Maryland's, right, because it's about the downstream co-benefits having to do with nutrient runoff and so forth into the Chesapeake. And so because you have agreements and regulatory standards, as well as voluntary measures, that has increased the incentive for farmers and other folks to take this seriously.

So there are other places that could do that. For example, my home State of Kansas, the amount of our croplands that are under cover crops is something on the order of less than 5 percent whereas in Maryland it's close to 50 percent, so there's huge discrepancies between the States, and that comes down to this question of incentives and how do we make this balance of regulatory standards plus incentives to achieve those co-benefits like water management, clean water for drinking, biodiversity benefits, and so forth.

Ms. WEXTON. We can't just use one side of the ledger. We have to do the incentive as well as the requirement. OK. Very good. Thank you very much. And I will yield back the balance of my time with that.

Mr. BEYER. Thank you very much. The Chair recognizes the gentleman from Tennessee, Congressman Cohen.

Mr. COHEN. Thank you, sir. I missed the earlier part of the hearing. And did anybody talk about the effect of climate change on human health? A little bit, Dr. McElwee. What issues might be pertinent to Memphis? And it gets hot in Memphis and all through the south, and the south is known for a lot of kidney stones, the heat belt and stroke belt. As it gets hotter and hotter, people drink more tea and get more kidney stones. What are the different illnesses and maladies that will beset people because of climate change that you have ascertained?

Dr. MCELWEE. I'm not a health expert, but based on the National Climate Assessment that came out last year for the United States, certainly heat waves. And that's what we had talked about with Representative Crist earlier. We know that heat waves and extreme heat events are going to increase as our emissions and our temperatures continues to rise. And so there are a number of health effects that are associated with those heat events. And they certainly tend to be exacerbated in urban areas where we have urban heat island effects as well. So certainly that's an area where the human health effects and so forth, the damages around that need to be weighed.

We've talked a lot about, well, what are the costs of action. I really want to emphasize there are costs of inaction. And those include the health impacts of these extreme events that we are increasingly seeing and our National Climate Assessment points out that it is really the southern region that is going to be seeing those as we move forward.

Mr. COHEN. Yes, ma'am.

Ms. FRANSEN. The other angle that I would speak to on that—and I agree with absolutely everything that Dr. McElwee said—when we're talking about health and climate change, it's not only the health impacts of climate change itself but the health benefits that we can derive by getting off of fossil fuels. And in particular air pollution and all the health impacts that stem from that, in terms of asthma, heart disease, et cetera pose very serious both human and economic costs.

One analysis that I'll mention that WRI was involved in found that measures to cut U.S. emissions about in half by 2030 would actually generate up to around $56 billion in health benefits in 2030 primarily as a result of avoiding air pollution. Thank you.

Mr. COHEN. Is it Heidi Mountain?

Dr. STELTZER. It is. I love that that's happened here, too. It's easier in the mountains. Everybody's ready to gravitate to that.

Mr. COHEN. It's Beyer's fault.

Dr. STELTZER. I was just going to share that there's the direct effects when we think about it's a hotter, drier planet. And then we have to recognize all of the ecosystem-level changes, the atmospheric changes that go along with that, and it's hard to trace everything that goes back to how healthy is any one human, our communities at large. Resilience says we want to put health first and foremost and take care of people, and so that's an important piece. So if we have a warmer, drier planet, then we have more fires. And when we have more fires, we have air pollution.

And we also have a loss and feeling of control. And what we haven't mentioned yet, and this isn't my expertise, but it ties into mental health. And so much of our human well-being depends on where and how we feel about what we do and don't have control over in our world.

Mr. COHEN. Let me go from there. Your people-first is a great idea but animals second and the fires in Australia and koalas. Darwin made it to Australia, didn't spend a lot of time there on the Beagle or getting off the Beagle, but he did think about evolution when he was there when he saw the platypus and thought about them—and some other animals there that seemed obscure, and this unique area had such unique animals.

What are we possibly losing in terms of extinction? I mean, there's some effort to put koalas on the extension list. Are there other little tiny little varmints that might have disappeared?

Dr. STELTZER. I have to say I read the news a lot since the fires got big and vast. They name a lot of unique species that I don't know well even though I've been to Australia because, as you mentioned, they're small or they're unusual. What I can tell you is that it's incredible to go someplace and see an animal that doesn't look like anything you could have even imagined. Wombat, they've been on the news a little bit, not as much as the koalas, and that's because species differ in their capacity to keep themselves safe. Kangaroos are less impacted because they ran away. Koalas are slow and have a very unique food source. They're kind of stuck. Wombats dug underground. That's where they live is underground, and so they weathered, you know, the firestorm literally across their habitat. And now they're struggling for food.

So, you know, some of the relief efforts that are going to Australia and care of animals is where and how can you provide food and animal water to animals that can't get to accessible food and water. And that's something that, you know, people in America can help contribute to.

Mr. COHEN. Yes, Australia is a unique area for its flora and its fauna and some of it is jeopardized.

If I can have a few extra minutes since there's nobody here to—thank you, sir.

Climate change, important, serious, top of the chain. Technological advancements that threaten the environment, too, like plastic and the large amounts of plastic that's floating out there in the Pacific Ocean and that interfere with birds and fish and eating and killing and dying and blah, blah, blah, and Midway Island. Anybody got any experience on plastic and what we—yes, sir, please.

Dr. MURRAY. Given that you're from Tennessee, I'd just like to draw attention to Eastman Chemical Company——

Mr. COHEN. I'm from Memphis. It's just about a different part of the world.

Dr. MURRAY. I'm from Boston, so——

Mr. COHEN. You're closer to Eastman——

Dr. MURRAY [continuing]. Tennessee——

Mr. COHEN [continuing]. Than I am.

Dr. MURRAY [continuing]. I'm closer. Yes, exactly. Right.

But anyway, there's a lot of interesting industry-academic partnerships, and we're learning more as we can about plastics in the ocean and microplastics in the ocean. We truly don't have agreed-upon definitions of how small a microplastic is or how big it gets before it's something else. We don't understand the physical transport of it. We don't understand how it's transported down into the deep sea. We don't understand how one company's plastic might be different from another company's plastic in terms of how it degrades or is preserved in the environment.

So, like many things in ocean sciences or land sciences or energy sciences, we are still in many ways in the gathering-information mode. And particularly in the oceans we don't know what's out there, and we don't understand how it works. So we talk about oceans and human health, which is an NSF, NIH (National Institute of Health) jointly studied, jointly supported program. They are interested in the impact of the oceans on human health.

We don't understand about the plastics, how plastics propagated up the food chain or downward, which is why my, you know, singular recommendation to you folks in my written testimony is we need more ocean observations. We need more terrestrial observations. We need to get that data there that you folks can then use to write informed legislation that makes sense. It makes sense financially, it makes sense socially, but also makes sense in that it's going to work. It's going to actually be targeting the right thing. And I think listening to this conversation here today, that's a unifying thing that I see coming.

Mr. SHELLENBERGER. Can I add one thing to your question?

Mr. COHEN. Sure, please.

Mr. SHELLENBERGER. The one thing we do know is that what determines whether or not significant amounts of plastic waste make it to the ocean is whether or not a nation has a waste collection and management system, so we know that most of that plastic waste in the ocean is coming from countries that don't have waste collection and management systems. And the countries that don't have waste collection and management systems are poor countries, so it's another kind of case of why we need economic development.

Mr. COHEN. But even when we have waste collection systems, if we don't get rid of single-use plastics—and I commend my Chair for having these glasses and water that we can pour rather than continue to use these single-use plastics, which so many of the Committees do, which is just awful to watch and witness, but we've got to get rid of single-use plastics or we're going to continue to spoil our environment, I mean, and kill animals.

Mr. SHELLENBERGER. Yes, but we need waste management and collection systems to prevent that plastic from going into the oceans. This is the major finding of the JanPak study from 2015.

Mr. COHEN. Well, that's true, but if we don't have all that plastic because we don't have single uses we have less need to do that. But beyond that, I wanted to talk to you anyway.

Mr. SHELLENBERGER. Yes. OK.

Mr. COHEN. You talked about Senator Alexander, and he's my friend and he might be for witnesses and be for common sense and the Constitution and fairness and justice and all those things, but he's not necessarily in favor of Bellefonte being redone. And you know Bellefonte in Alabama, do you not?

Mr. SHELLENBERGER. I do.

Mr. COHEN. And there's a private group called Nuclear Development that wants to develop Bellefonte, and they want to do it privately and think they can do it. Would that not be something we need to pursue and that's maybe where Lamar has a little error in his otherwise stellar record on nuclear?

Mr. SHELLENBERGER. Possibly, although my big point on nuclear is that we need a national nuclear strategy. And so we've got to get away from this hodgepodge potpourri nuclear and to have something approaching what we were doing in the 1950s or something that's much more similar to what the Russians and Chinese are doing. Otherwise, it's just a kind of every day some new nuclear project that we kind of project our hopes onto, but it's not actually a plan.

Mr. COHEN. But do you know anything about the Bellefonte plant? Do you know how practical that is? I mean, they've got some experts from Canada working on it.

Mr. SHELLENBERGER. I mean, I'm the most pro-nuclear person I know, so, I mean, I'm in favor of doing more nuclear. But I'm here to say that we've had decades of people being like why don't we try this, why don't we try that, and that's not a plan. The Chinese and Russians have a plan. And if we're ready to cede this dual-use technology to the Russians and Chinese, we should make that decision because right now we're just sleepwalking into it.

Mr. COHEN. Let me close out with that. I'm happy to hear the Russians have a plan because if the Russians have a plan, then Trump will have a plan.

I yield back the balance of my time.

Mr. BEYER. Mr. Ranking Member, sir?

Mr. LUCAS. I would just note in my observation that one of the things that I am most enamored with about Memphis is the awesome barbecue, and thank goodness for that beef barbecue and pork barbecue and chicken barbecue and all those wonderful things that you produce.

Mr. COHEN. You're welcome.

Mr. LUCAS. Yield back. Move to adjourn.

Mr. BEYER. Before we adjourn, Mr. McAdams had mentioned a special NOAA report, so before this hearing comes to a close, I'd like to submit for the record an announcement from the National Oceanic and Atmospheric Administration and NASA that just came out at 11:00 a.m. this morning. Separate analyses from NOAA and NASA have both concluded that 2019 was the second-hottest year on record for the Earth, falling just behind 2016. The average temperature in 2019 across the Earth was 1.71° Fahrenheit above average. And, further, NOAA finds that in 2019 the ocean heat content was the highest in recorded history.

So, without objection, we'll submit this for the record.

And before closing, I want to thank the witnesses very much for coming and testifying before our long hearing today. And the record will remain open for 2 weeks for additional statements from the Members and for any additional questions the Committee may ask of the witnesses.

So, without objection, the witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 12:49 p.m., the Committee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

POST-HEARING QUESTIONS SUBMITTED BY MEMBERS

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on the Climate Crisis: From Science to Solutions"

Questions for the Record to:
Ms. Taryn Fransen
Senior Fellow
Global Climate Program
World Resources Institute

Submitted by Chairwoman Eddie Bernice Johnson

1. What are the most urgent mitigation and adaptation needs, and what are the greatest barriers to achieving these goals?

2. What investments should this Committee be making in federal research and development efforts in the immediate future to further develop and implement effective mitigation and adaptation strategies?

3. On what scale should these investments be made?

4. How do new climate change scenarios developed by the International Energy Agency compare to scenarios evaluated by the Intergovernmental Panel on Climate Change, and what do they imply for current projections on global temperature rise?

5. To what extent do variability, cost, and land-use requirements pose prohibitive constraints on the expansion of renewable energy resources in the United States?

6. What does our energy future look like?

7. How can communities have a voice in what powers our world?

8. Is there anything else that you would like to address that you did not get a chance to at the hearing?

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on the Climate Crisis: From Science to Solutions"

Questions for the Record to:
Dr. Pamela McElwee
Associate Professor of Human Ecology
School of Environmental and Biological Sciences
Rutgers, The State University of New Jersey

Submitted by Chairwoman Eddie Bernice Johnson

1. Can you talk more about the role of anthropology in studies of climate change and why it is so crucial that anthropologists have a seat at the table?

2. What types of interventions in the food system can mitigate the risks to the food system from climate change?

3. What are barriers to implementing policy, technological, and behavioral change in the food system, and are there models in other countries that the United States should look to in this area?

4. How can improved accessibility and quality of information of the co-benefits of response options optimize sustainable land management?

5. Why are there limits to planting trees or crops as a solution to land degradation and climate change?

6. Is there anything else that you would like to address that you did not get a chance to at the hearing?

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on the Climate Crisis: From Science to Solutions"

Questions for the Record to:
Dr. Heidi Steltzer
Professor of Environment and Sustainability
Fort Lewis College

Submitted by Chairwoman Eddie Bernice Johnson

1. Is there anything else that you would like to address that you did not get a chance to at the hearing?

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on the Climate Crisis: From Science to Solutions"

Questions for the Record to:
Mr. Michael Shellenberger
Founder and President
Environmental Progress

Submitted by Chairwoman Eddie Bernice Johnson

1. What are the most urgent mitigation and adaptation needs, and what are the greatest barriers to achieving these goals?

2. What investments should this Committee be making in federal research and development efforts in the immediate future to further develop and implement effective mitigation and adaptation strategies?

3. On what scale should these investments be made?

4. Is there anything else that you would like to address that you did not get a chance to at the hearing?

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on the Climate Crisis: From Science to Solutions"

Questions for the Record to:
Richard Murray, PhD
Deputy Director & Vice President for Research
Woods Hole Oceanographic Institution

Submitted by Chairwoman Eddie Bernice Johnson

1. Is there anything else that you would like to address that you did not get a chance to at the hearing?

Questions for the Record – Vice Chair Ami Bera
Full Science, Space, and Technology Hearing
January 15, 2020 at 10:00 a.m.
"An Update on the Climate Crisis: From Science to Solutions"

Dr. McElwee

1. California Wildfires: My constituents are very concerned about the increasing frequency and destruction of wildfires in California. These wildfires have tragically caused more than a hundred deaths, consumed tens of thousands of homes and businesses, and burned millions of acres over the last few years. While Congress has taken steps to reduce the risk of wildfires through bipartisan disaster prevention efforts and relief funding measures, more will need to be done as our climate continues to change.
    a. What work can be done in mitigating the conditions of land degradation, drought, and outdated electrical infrastructure that we know are driving the uptick and high intensity of wildfires in California?
    b. What research gaps exist in understanding fire behavior, and what research programs or initiatives might fill these gaps?
    c. What are the biggest obstacles to reducing the risk of future fires? What can Congress do to encourage the adoption of practices or technologies to mitigate fire risk?

Dr. Steltzer

2. We know that increased warm weather caused by climate change will cause more winter precipitation to fall as rain. This will create thinner snowpack leading to more runoff water earlier in the season. In the 2019 Intergovernmental Panel on Climate Change Special Report on the Oceans and Cryosphere chapter on High Mountain Areas, for which you were the lead author, it is noted that for California and the Southwestern USA, a shift to peak snowmelt earlier in the year would lead to economic losses estimated at 10.8-48.6 billion USD by around 2050. In addition, we know that our current water storage and conveyance system in California needs to be modernized to adjust to the changing period of peak snowmelt.
    a. In the above illustrated scenario, what would be the primary industries affected by this change in peak snowmelt and what needs to be done to preserve snowpack and runoff in ways that will support said industries?

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"An Update on the Climate Crisis: From Science to Solutions"

Question for the Record

Submitted by Rep. Jerry McNerney

Question for Dr. Steltzer: How fast are impacts on the Arctic and cryosphere moving relative to model predictions and in your view, how close are we to dangerous tipping points?

Question for Dr. Steltzer: Do the risks of abrupt change—such as the collapse of the West Antarctic Ice Sheet, which would cause catastrophic sea level rise—indicate that we should think seriously about technological interventions such as reflecting sunlight from the atmosphere to maintain stability?

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Pamela McElwee

Responses from Dr. Pamela McElwee for the record from hearing on "*An Update on the Climate Crisis: From Science to Solutions*"

1. Can you talk more about the role of anthropology in studies of climate change and why it is so crucial that anthropologists have a seat at the table?

Mitigating and adapting to climate change is ultimately a human problem. Although we need a diverse variety of scientists to help us understand how the earth system works and what the physical and natural world does in response to climate change, we also need social scientists to help us understand how people react, adapt, and adjust their lives too. Some of this work has been done as part of the U.S. Global Change Research Program's Social Science Coordinating Committee, and anthropologists have particular skill sets in this area. Given that all global climate changes are experienced at the local level, although with highly variable impacts, anthropologists have been working in both the US and around the world at the forefront of vulnerability and adaptation studies. For example, anthropologists have examined the important roles of memory, narrative and emotion regarding interactions between people, landscapes and climate; noted the importance of documenting cultural values impacted by changing climates, including community, identity and sense of place; how changes in cosmology, cognition and belief may be required for communities to make sense of rapid climate shifts; and the impact of climate change on culturally-specific resource use practices.[1]

Anthropologists have also worked on definitions and ideas regarding the social construction of vulnerability. The IPCC has long defined vulnerability as a function of exposure, sensitivity and adaptive capacity, but anthropologists have pushed us to examine other very important variables that go into vulnerability – including issues such as resource access, cultural frames and issues, institutions and governance, and access to information.[2] Anthropology has a long history with the concept of adaptation through interest in how communities and cultures interacted with their environment over time. For example, archaeologists have examined climate impacts in long historical time frames to understand maladaptive outcomes, such as food systems and civilizational collapses in past centuries.[3] Anthropologists have also noted that values and risk perceptions are very much culturally determined and potentially can prevent proactive adaptation.

Anthropologists are also analyzing the drivers of climate change – namely, energy use and consumption – and how better understanding of the cultural determinants of these drivers can help design mitigation policy.[4] For example, work on needed energy transitions points out that this area projects a lot of technological optimism and tends to neglect consideration of equity and justice. Anthropologists have also examined different policy pathways and incentives, such as

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[1] O'Reilly, J., Isenhour, C., McElwee, P.D., and Orlove, B. (2020) "Climate change: engaging anthropological possibilities." *Annual Review of Anthropology*, vol 49 forthcoming.

[2] Thomas, K. et al. 2019. Explaining differential vulnerability to climate change: A social science review. *WIREs Climate Change* 2018;e565

[3] Nelson, M. C., et al. (2016). Climate challenges, vulnerabilities, and food security. *Proceedings of the National Academy of Sciences, 113*(2), 298–303.

[4] Fiske, S., et al. (2018). *Drivers and responses: Social science perspectives on climate change, part 2.* Washington, DC: USGCRP Social Science Coordinating Committee. https://www.globalchange.gov/content/social-science-perspectives-climate-change-workshop.

development of market-based environmental governance that uses capital investments and individual responsibility, but which may present barriers to coordinated action. Anthropological researchers are engaged in trying to understand why, despite education and other policy campaigns, consumption emissions continue to rise, and what structural barriers people face in mitigating emissions.[5] Thus, getting more anthropologists involved in future climate modelling and projections, such as through refined Shared Socioeconomic Pathways, will make these scenarios even more robust and useful for planning in the future.

2. What types of interventions in the food system can mitigate the risks to the food system from climate change?

We need to be proactive in talking about how farmers and other food producers, retailers and processors, and consumers are all going to be impacted by climate change, and what they can do to mitigate and adapt to it. The IPCC Land report's message on the impact of rising temperatures on food supplies is very clear—climate change is going to make food production and supply for a growing global population even more challenging. [6] US farmers will have to be an important part of meeting this challenge.

The food system is both vulnerable to climate impacts and a source of emissions that increases our climate risks. Crop and livestock production in the US is projected to be negatively affected both by direct and indirect climate impacts, namely increasing temperatures that cause heat stress in plants and animals; changes in rainfall that can cause droughts and floods, making it harder to grow crops in certain seasons and certain places; and reduced crop quality, such as a decline in micronutrients in some staple crops as a result of CO_2 fertilization.[7] How serious these impacts will be depends how high emissions levels and correlated temperature increases will be, and on our ability to adapt. One important point of our report is that many of these challenges are already here: we are already seeing yield reductions in some crops in the low-latitudes, and regional food production declines and food price instability following extreme events, like the heat and droughts in southern Europe last summer. Targeted policies encouraging more productive and resilient agricultural production systems and the importance of incorporating complementary policies (such as safety-net programs for producers) can compensate or counteract the impacts of climate change in these vulnerable areas.[8]

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[5] Isenhour, C., & Feng, K. 2016. Decoupling and displaced emissions: on Swedish consumers, Chinese producers and policy to address the climate impact of consumption. *Journal of Cleaner Production, 134*, 320–329. https://doi.org/10.1016/j.jclepro.2014.12.037

[6] Mbow, C., Rosenzweig, C. et al. 2019. Ch 5: Food Security. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.

[7] Mbow, Rosenzweig et al, 2019, ibid; Gowda, P., J. et al. 2018: Agriculture and Rural Communities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 391–437. doi: 10.7930/NCA4.2018.CH10

[8] IPCC. 2019. Summary for Policymakers. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.)]. Geneva: IPCC.

Our food systems are also responsible for GHG emissions, which increase our climate risks. These emissions come from the production and distribution of food from producer to consumer, including transport, retail and food loss/waste. The livestock sector is a particular contributor to GHG emissions, accounting for close to 15% of total global emissions (including methane emissions from ruminants, emissions associated with feed production or land use change, manure management emissions, transport, and other sources). Unless we overhaul our global food system, we will not be able to limit temperature rise in line with the Paris targets. Yet if we farm more efficiently, and on less land, that would free up agricultural land for afforestation and bioenergy production if we need them to make a dent in negative emissions to hold warming to below 2 degrees or below.[9]

Some tweaks to policy affecting our agricultural systems in the US could make a difference. The SRCCL report did not lay out specific recommendations, as the IPCC's work is to be policy-relevant, but not policy-proscriptive. However, some of the conclusions of the report can be tied back to specific policy interventions, and I lay out a few that are most promising in my opinion. For example, linking crop insurance to better land management would help. There is evidence that the way we do subsidized crop insurance in the US both encourages land use change (that is, conversion of natural ecosystems to farmland) and doesn't incentivize farmers to invest in low-emission agriculture or climate adaptation measures. Our extension services could encourage more experiments in low-carbon agriculture, and climate friendly loans could be made to farmers (that is, loans for low-emissions agriculture, or loans that have reduced interest rates or longer payback terms when farmers experience climate impacts).

Soil carbon is also a hugely important carbon sink, as well as a good way to help farmers adapt to climate change, as healthy soils tend to have better resilience to floods and droughts. However, we haven't had good ways to incentivize healthy soils in the US. We tried a voluntary market back when we had the Chicago Climate Exchange, but there were not enough buyers and the price eventually collapsed. So, we need a combination of market and regulatory forces to tackle the soil carbon challenge. Right now in California there are new Climate Smart Agriculture programs in which farmers and ranchers are paid to practice on-farm management that sequesters carbon and reduces methane emissions.[10] Farmer response to these programs is strong, with twice as many farmers applying than program funding can support. More funding in more states, and making the processes easier for farmers and ranchers to negotiate their way in these programs, would help. The key with these types of programs is consistency and dependability so farmers can plan in advance.

Other forms of government subsidies could be altered to reflect climate goals, e.g. the Conservation Reserve Program (CRP) could be extended to more lands, or the Conservation Stewardship Program (CSP) oriented more to climate emissions reductions. We want to make sure where we produce biofuels we are doing so smartly; for example, we can ensure that biofuels are not produced on newly converted lands, especially those that have been in CRP or

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[9] IPCC. 2018. Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., et al. (eds.)]. Geneva: IPCC.

[10] http://ciwr.ucanr.edu/Programs/ClimateSmartAg/Healthy_Soils_Program_HSP/

CSP.[11] The IPCC Land report also noted other potential solutions specifically for the livestock sector, including targeting reductions in enteric methane through food additives; reductions in nitrous oxide through manure management; sequestering carbon in pastures; and implementation of best practices in animal husbandry, breeding and management, all of which would have an effect on GHG emissions reductions in this sector.

3. What are barriers to implementing policy, technological, and behavioral change in the food system, and are there models in other countries that the United States should look to in this area?

One of the biggest barriers to change are demand-side pressures; these result from policy support for certain types of agricultural products (such as subsidies) and behavioral choices for diets that require more land and water and cause more emissions of GHGs than others (e.g. red meat and dairy, although emissions vary significantly across different production systems.) The average American consumes nearly three times the global average of beef, for example, and while beef contributed only around 3 percent of the calories and 12 percent of the protein in the average U.S. diet, it accounts for 43 percent of the annual land use and nearly half of the production emissions.[12] Changing diets globally could save a considerable amount of emissions from agriculture, of up to potentially 20 GtCO2-eq yr^{-1} by 2050 according to the IPCC Land report. For the US, a shift in consumption towards a broadly healthier diet would decrease GHG emissions from food production by 11% and decrease land use by 32%.[13]

Food waste generates GHG emissions that are significant as well. For the US, the emissions associated with our food waste are equivalent to 33 million average passenger vehicles annually. The EPA also says food waste and packaging account for 45% of materials sent to landfills. Many groups are working on this, from zero waste restaurants to bans on food waste in landfills in some states. At my home institution of Rutgers, we implemented a wasted food diversion plan from the cafeterias and dining halls on campus. In addition to diverting food for animal feed, Rutgers also uses a food waste pulper that pulverizes food scraps and removes excess water, which reduces the volume by up to 80 percent. Although the pulping machine has upfront costs, Rutgers saved almost twice as much ($100,000) in just one year in avoided landfill hauling costs.

Yet a major barrier for the US to tackle these problems continues to be the fact that there is no incentive to reduce GHGs as long as these remain externalized costs. Without effective emissions pricing or other policies that fully recognize the damage of GHG emissions, it is unlikely that emissions will decline on their own from the agricultural and land sectors. Emission pricing in the form of a tax or trading scheme has been shown to be broadly effective in reducing emissions over time in the energy sector in other countries, but we do have less evidence for how emissions pricing might work in the land sector. Monitoring, reporting and evaluation practices would need to be enhanced for emissions pricing or trading schemes to work for agriculture.

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[11] Lehner, P. and N. Rosenberg (2019). Agriculture. In *Legal Pathways to Deep Decarbonization in the United States*, M. Gerrard and J. Dernbach, eds. Washington DC: Environmental Law Institute.
[12] World Resources Institute. (2019). *Creating a Sustainable Food Future: A Menu of Solutions to Fee Nearly 10 Billion People by 2050.* Washington DC: WRI, World Bank, UNEP, UNDP, CIRAD and INRA
[13] Birney, C. et al (2017). An assessment of individual foodprints attributed to diets and food waste in the United States. *Environ. Res. Lett.* 12 105008

Some industry groups have opposed carbon fees and taxes or carbon reporting because they fear it will increase costs to farmers, but there is evidence it would be the opposite – that farmers could gain extra income from their carbon-conserving practices by incentivizing best practices.

4. How can improved accessibility and quality of information of the co-benefits of response options optimize sustainable land management?

The land sector is both threatened by, but can also potentially be a way to reduce the many impacts of, climate change. Land is a hugely important carbon sink, absorbing around one-third of anthropogenic CO_2 emissions, and we need to ensure it continues to supply us with this free subsidy from nature. There are many co-benefits that can be derived from sustainable land management and better protection of natural ecosystems.[14] For example, here in the US, we could do a better job in getting our pasture systems working as carbon sinks; improvements in half the existing grazing land area to encourage more healthy soils could be a sink for 10-23% of total US CO_2 emissions from other sources. The Soil Value Exchange in eastern Coastal Texas is an example of how to incentivize ranchers to provide more of the public benefits we get from sustainable land management, including important co-benefits like flood control.[15] In this model, through raising cattle, incentives for carbon farming, and other leases on land, a rancher could generate multiple income sources. These types of co-benefits need to be better publicized and incentivized so that more people have opportunities to participate and gain from them. Improvements in partnerships of farmers and ranchers, scientists, land grant universities, industry and agribusiness, and state and federal agencies on land and climate co-benefits would be one place to start.

5. Why are there limits to planting trees or crops as a solution to land degradation and climate change?

Planting trees, preserving and restoring forests and other carbon-rich ecosystems, and planting energy crops are all of potential help in mitigation, but they have to be balanced. Land is a finite resource and we need to pay close attention to what we plant, where, and why, otherwise we could take away land that is vital to feeding a growing population, or land needed for biodiversity conservation, or even raise temperatures if we get it wrong. Any land solution also has to be combined with fossil fuel reductions; you can't do one without the other and hope to limit warming to 2 degrees or less.[16]

Planting trees has been posited as a quick-fix solution to climate change. Yet while trees certainly can help in mitigation, they are not a silver bullet. For trees and soils to be effective carbon stores takes time. There are risks from damage to them (e.g. through wildfires) and eventually they will no longer continue to take up carbon and will need to be replaced. There can be significant trade-offs (with impacts on land degradation, food security, and biodiversity) with larger-scale monoculture plantations, even though those may be taking CO_2 out of the

[14] Smith, P. et al. 2019. Which practices co-deliver food security, climate change mitigation and adaptation, and combat land degradation and desertification? *Global Change Biology* in press DOI: 10.1111/gcb.14878
[15] Blackburn, J. et al. (2018) The Soil Value Exchange: Unlocking nature's value via the market. *Bulletin of the Atomic Scientists*, DOI: 10.1080/00963402.2018.1461974
[16] Anderson, C.M., et al. 2019. Maximize natural climate solutions - and decarbonize the economy. *Science* 363, 933-934. doi: 10.1126/science.aaw2741.

atmosphere. Very large areas of the world have been suggested for afforestation, such as that proposed in the ongoing "Trillion Tree" initiative. However, when safeguards are introduced (e.g., excluding existing cropland for food security, not planting boreal areas which increases albedo and warms the surface, including diverse use of local species, etc.), the amount of area available for planting is at maximum around 680 million ha. Without such instituting such safeguards and wisely planting trees in the right places, afforestation could negatively impact food security. For example, large-scale plans without safeguards would be projected to increase food prices by 80% by 2050.[17]

Bioenergy can play a role if done well, but it depends on a variety of factors. There have been questions about the indirect emissions associated with bioenergy production, such as land conversion emissions and rebound effects. The long-term viability of biofuels also depends on the rate of technology innovations in other energy options for transportation, such as progress on costs and storage in electric cars. But certainly, we can do a better job in how we produce biofuels in the US; for example, moving away from annual corn cropping for ethanol to perennial grasses could transition the Midwestern corn-belt region from a source to a sink of GHGs due to projected increases in soil carbon. There has been much work to identify the next generation of crops that will provide the best future solutions and the evidence is clear that perennials such as switch grasses and trees such as willow have a large potential. Essentially our best bets are likely to be bioenergy crops that don't tend to compete with food crops for the same land (e.g. that can be grown in areas that would not be efficient for food production) and which have soil-improving properties and require fewer inputs.[18]

The other thing to keep in mind is that in most cases, reducing deforestation and other forms of land degradation to begin with may be more cost-effective than replanting trees or growing bioenergy. Mature forests should be prioritized in terms of protection and retention because they provide higher carbon stocks than newly planted trees. Reducing deforestation and forest degradation lowers GHG emissions overall, with an estimated technical mitigation potential of 0.4–5.8 GtCO2 yr^{-1} globally.

6. Is there anything else you would like to address that you did not get a chance to during the hearing?

I would like to correct a few of the statements Mr. Michael Shellenberger made in his written and oral testimony, notably where he cited scientific literature but misinterpreted or misrepresented the findings. This is particularly important as his written testimony states that he was motivated to testify due to "care about getting the facts and science right" (p. 1). Let me help him do so below, with particular reference to inaccurate statements he makes that are not reflective of findings in the recent IPCC Climate Change and Land Report and Oceans and Cryosphere Report.

[17] Kreidenweis, U. *et al* 2016 Afforestation to mitigate climate change: impacts on food prices under consideration of albedo effects. *Environ. Res. Lett.* 11 085001
[18] Davis, S. et al. 2013. Management swing potential for bioenergy crops. *Global Change Biology Bioenergy* 5: 623–638, doi: 10.1111/gcbb.12042

1. Food production in a warming world. First, Mr. Shellenberger states that according to a Food and Agriculture Organization (FAO) report, "crop yields will continue increasing even in high-warming scenarios".[19] Let me explain more thoroughly why this report should not be taken as a prediction of crop yields under climate change. This particular study uses primarily economic modelling of future pathways for food and agriculture through three distinct scenarios (named business as usual (BAU), towards sustainability (TSS), and stratified societies (SSS)). As the report states clearly, scenarios are "*not forecasts or predictions* [my italics] or even stand-alone projections, but rather possible, plausible and consistent pathways of what the future might look like at some, usually distant, point in time" (p. 5). These scenarios rely on certain assumptions, often rooted in past trends and experience, and there are significant challenges to incorporating the potential impact of short-term events, such as those associated with climate change, in such long-term foresight analysis. One cannot then say that such scenarios show food production "will increase" in the future, only that it is plausible in some scenarios, given certain assumptions.

In particular, I would like to point out that the sentence in Mr. Shellenberger's testimony that "farmers in sub-Saharan Africa could see crop yields increase 80 to 90 percent" in this FAO study is completely wrong. The actual sentence from FAO is: "In the SSS scenario, the greater inequalities and resulting disparities in spending on R&D for agriculture translate into increasing differences in yield growth across regions: low-income regions (SSA, parts of EAP, and parts of LAC)[20] achieve 80 percent to 90 percent of the yield growth they achieve under BAU conditions" (p. 76). In other worlds, one scenario (SSS) has lower yields (10-20% less) than another scenario (BAU); there is nothing in the report about Sub-Saharan farmers potentially achieving crop yield increases of 80% or more. The average increase in yield growth that is assumed in the SSS scenario (again, not predicted, but assumed) would result in an average 24% increase in crop yield over 2012 by 2050 (p. 76). Across all three scenarios, assumptions regarding technological innovation provide a range of 15-30% yield increases by 2050 (p. 76), and none of the 3 scenarios examined show anywhere near 80-90% yield increases in any part of the world (the highest outcome would be a potential 44% yield increase in Europe by 2050 in a BAU scenario with technology adoption; see p. 82).

These possible increases do not yet account for climate impacts, and so all the scenarios also make use of the FAO-IIASA Global Agro-Ecological Zones database which combines "data for land suitability, yield, and other variables using recent IPCC AR5 climate model outputs for four different representative concentration pathways (RCPs)" (p. 78). These results of these models "suggest that climate change will have mostly negative impacts on yields, with reductions of around 5 percent globally by 2050 compared with 2012, with non-marginal regional variations" (p. 77). Thus, if one is assuming yields will rise by up to 24% with technological innovation in the SSS scenario, and only suffer a 5% reduction due to climate change, the scenario in question would show that technology provides a stronger signal than climate for the future of agriculture in certain regions, particularly before 2050.

However, the FAO authors posit a number of caveats with this approach. First, it "relies on a crop model and so it does not account for a number of processes that could have negative impacts on yields, such as heat stress during critical crop growth periods." This is crucial, as

[19] FAO. (2018). The future of food and agriculture: Alternative pathways to 2050. Rome: FAO.
[20] Acronyms refer to Sub-Saharan Africa, East Asia and Pacific, and Latin America and the Caribbean.

other literature has indicated that heat stress in crops is a major factor in crop yield declines. [21] In addition, their approach relies on "simulated climate data from General Circulation Models (GCM) which may not capture small-scale and short duration features of the climate. Yields reported in this database could therefore tend to underestimate the potential impacts of climate change on crop yields" (p. 78). These are important caveats that indicate this report is *not a prediction of crop yields under climate change*, but instead is a way to put climate impacts at rather coarse resolution into scenario pathways for future agricultural outcomes. The results thus need to be taken for what they are, and not as a prediction of future yields, for which we should more accurately rely on crop-climate models or experimental simulations of future growing conditions (two other methods that are more representatives for this question).

In reality, the overall findings of the FAO study acknowledge the same problems with the food system under climate change as the IPCC land report: as the FAO report states, the scientific literature is clear that "climate change may significantly reduce yields in the long run" and that "elevated levels of carbon dioxide in the atmosphere that are likely by 2050 are associated with substantial declines in the zinc, iron and protein content of staple crops" (p. 31). The Executive Summary of the report further argues, in line with the IPCC Land Report, that "climate change already has negative effects on crop yields, livestock production and fisheries, particularly in low- and middle- income countries. Such impacts are likely to become even stronger later in this century" (p. xxi).

I would like to also go further and note that in addition to misunderstanding the FAO scenario report, Mr. Shellenberger's focus on food production being able to be solved with technological innovation is too narrow of a perspective. What the IPCC Land report concludes is that *climate changes are already affecting all four pillars of food security: availability, access, utilization,* and *stability*. Availability is related to yield and production, which vary by region. For example, in lower and mid-latitude regions, some food crop yields are already decreasing.[22] One study has asserted that climate change between 1981 and 2010 has already decreased global mean yields of maize, wheat, and soybeans by 4.1, 1.8 and 4.5%, respectively, relative to preindustrial climate, even when CO2 fertilization and agronomic advancements are considered.[23] Further, in the last 20 years, yield growth for most crops has actually slowed, with recent studies even suggesting that in selected regions yields are already close to their maximum potential.[24] While we can definitely focus on closing the yield gap in places where improvements can be made effectively, we are not going to see these production increases without substantial investment. So overall, the optimism that Mr. Shellenberger expresses about increases in crop yields is not borne out by the preponderance of the evidence of slowing yield improvements and confounding factors related to growth conditions for crops, particularly in the second half of the century.

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[21] Zhao, C., et al. (2017). Temperature increase reduces global yields. *Proceedings of the National Academy of Sciences* 114 (35): 9326-9331.
[22] Mbow, C., Rosenzweig, C. et al. 2019. Ch 5: Food Security. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.
[23] Iizumi, T, et al. (2018). Crop production losses associated with anthropogenic climate change for 1981–2010 compared with preindustrial levels. *Int J Climatol.* 38: 5405– 5417. https://doi.org/10.1002/joc.5818
[24] Ray, D., *et al.* (2012) Recent patterns of crop yield growth and stagnation. *Nat Commun* 3, 1293 https://doi.org/10.1038/ncomms2296

Additionally, Mr. Shellenberger's statement does not examine the other factors that affect food security beyond production. Access relates to ability to obtain food, including the impact of prices, and the 2010-2011 global food price spike limited access to food for millions by raising prices, and was initially triggered by the exceptional heat in summer 2010.[25] Grain price increases in that time period were also driven by longer-term trends like increases in consumption and increased demand for biofuels. Poor consumers can spend 50 to 70 percent of their budget on food, and the quality of diets tends to go down during such price spikes. In future scenarios, global crop and economic models project increases in cereal prices by 2050 due in part to climate change, leading to higher food prices and increased risk of food insecurity and hunger.[26]

With regards to utilization (which encompasses nutrition, cooking, and health) climate changes and an increase in the amount of CO_2 in the atmosphere are affecting the nutritive value and product quality of crops, a key finding of great concern. As I noted in my written testimony, higher CO_2 concentrations leave crops with lower nutritional quality, as plants accumulate less minerals (particularly iron and zinc).[27] Other concerns about the food supply under climate change include worries about increases in contaminating organisms, which can lead to reduced food quality and affect availability.

Finally, with regard to stability (that is, availability and access to food), climate disruptions are increasing in many regions, with visible impacts on food security, varying by crops produced and on other circumstances. The potential for multi-breadbasket failure (that is, multiple crops in a region or across regions failing at once) increases at higher temperatures as compound events may occur.[28] It can be very difficult to deal these this volatility. Essentially, we need coordinated multilateral action to increase access to markets, and improved options for risk management (e.g. insurance or food stocks) at national levels to cope with potential disruptions.

2. Risks from wildfires. Mr. Shellenberger cites scientists working on wildfire risk in the US and Australia as stating that human impacts are a stronger signal than climate change (e.g. where people live may have stronger influence on risk than the impact of temperature or drought risk per se). The study that is cited is very clear that their work does not dispute or diminish the role of climate change in increasing wildfire risk; rather, that depending on region, that risk can be amplified by other human decisions. But the signal from climate change is also clear in some regions (in the cited study, climate variables explained more than 50% of the variation in fire activity in some places).[29]

We know that rising global temperatures lead to more frequent heatwaves and associated droughts, which are conducive to fire weather, and fire weather seasons have increased nearly

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[25] Mbow, Rosenzweig, et al. 2019, *ibid.*
[26] IPCC. 2019. Summary for Policymakers. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.)]. Geneva: IPCC.
[27] Myers, S., et al. 2014. Increasing CO_2 threatens human nutrition. *Nature* 510: 139–142.
[28] Zscheischler, J., et al. 2018. Future climate risk from compound events. *Nature Climate Change* 8: 469–477.
[29] Syphard, A. et al. 2017. Humans diminish climatic influence on wildfire. *Proceedings of the National Academy of Sciences* 114 (52): 13750-13755; DOI:10.1073/pnas.1713885114

20% since 1979.[30] For example, the IPCC AR5 report in 2014 stated that we would expect an increase in fire weather (hotter and drier) in most of southern Australia, with an increase in the number of days with extreme fire danger risks rising up to 30% higher by 2020 and up to 100% higher by 2050. So far the prediction for 2020 has been accurate and demonstrated in Australia's terrible recent summer fire season. More than three-quarters of Australia saw its worst fire conditions on record in December 2019, with the average maximum temperature for the continent above 40°C for 11 days. The average daytime temperatures in December were more than 4.15°C above the 1961-90 average for the region, according to the Bureau of Meteorology.[31] The Black Saturday fires in Victoria in 2009, which also caused much devastation, bore a similar fingerprint – they occurred in hot, dry summers with consecutive days over 30°C. These types of risks will continue to increase, barring significant mitigation action on climate change, and are exacerbated by other human influences, such as continuing to build homes in fire-risk zones, which will extend in geographic area in future years as well due to climate change.

3. The impact of natural disasters. Mr. Shellenberger's written testimony states that "While it is sometimes possible to discern the influence of climate change on natural disasters, that influence is often overshadowed by improved resilience, including by poor nations. The decadal death toll from natural disasters declined 92 percent from its peak in the 1920s. In that decade, 5.4 million people died from natural disasters. In the 2010s, just 0.4 million did. Moreover, that decline occurred over a period when the global population nearly quadrupled. A major study in the journal *Global Environmental Change* last year found that the rates of death and economic damage had dropped by 80 to 90 percent over the last four decades."[32]

Overall, this study was aimed at showing that "improved protection against hazards has counter-balanced the effects of increasing exposure on disaster risk" (p. 7), but that vulnerability is in fact still differentiated between richer and poorer countries. In other words, the decadal averaged declines in deaths and damages examined in this study were primarily due to better warning systems and improved responses to disasters and *does not show that disasters are decreasing or that climate change is not implicated in many extreme events.* Indeed, the frequency and intensity of many extreme events are in fact *increasing*, and we can see clear fingerprints of climate change in this, such as in the increase in extreme heat events.[33] Just because we have gotten better at predicting and adapting to these events as compared to the past does not mean that they are not significant, nor does it mean we will be able to adapt indefinitely.

Indeed, in terms of estimating costs of future natural hazard and climate damages, extrapolating from the past is not necessarily the most useful approach for predicting the future. Use of climate models that compute "damage functions" to determine the impacts to economies (including

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[30] Sukumar, R. et al. 2019. Cross-chapter box 3: Fire and Climate Change. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.)]. Geneva: IPCC

[31] https://www.smh.com.au/environment/weather/year-of-extremes-as-record-heat-fire-danger-and-dismal-rainfall-dominate-20200108-p53psq.html

[32] Formetta, G & L. Feyen. 2019. Empirical evidence of declining global vulnerability to climate-related hazards. *Global Environmental Change* 57: 101920.

[33] Jia, G., E. Shevliakova, et al. 2019. Pages 144-150 in Ch 2: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds.]. Geneva: IPCC.

agriculture, infrastructure and health) are one way to estimate future costs. One such estimate suggest that the U.S. economy could lose about 1.2 percent of GDP per year for every degree C of warming, effectively halving the country's annual growth to 2050. This is because, depending on the emissions scenario, harvests will likely dwindle, summer energy costs will soar, rising seas will damage real estate and infrastructure, and heatwaves will lead to more cardiac and pulmonary disease. These costs are estimated to grow over time up to 2100 and beyond, and are highly variable by region, with higher damages in the South and Southwest US.[34]

4. The limits to adaptation. In Mr. Shellenberger's written and oral testimony, he stated that because the Netherlands has been able to apply engineering solutions to their flooding and sea level rise (SLR) problems for centuries, that other countries (like Bangladesh) should also be able to do so. The implication from this is that we do not need rapid mitigation action because we can adapt our way out of the problem. In reality, it costs the Netherlands billions of euros each year to keep that system working and will cost billions more for them to raise dikes higher to adjust to rising SRL, and they are a rich country.[35] Bangladesh is not and will have considerable challenges to raise the money required to adapt to higher rates of coastal erosion, increasing salinity, and other problems associated with SLR. Costs of adaptation to SLR alone have been estimated at a wide range, with potential global coastal protection requiring yearly investment and maintenance costs of up to $170 billion a year later this century, even in low emissions scenarios.[36] Given that Mr. Shellenberger also states in his testimony that targeted aid for adaptation in developing countries would be "a mistake" (p. 8), it is unclear how he suggests that vulnerable countries like Bangladesh or Vietnam are able to overcome these SLR challenges on their own. As the *Global Environmental Change* study cited earlier in his testimony states clearly, "poorer countries remain particularly vulnerable to these hazards [coastal floods and winds] and that huge investments or changes in these societies may be needed to further reduce their vulnerability to them. For example, implementing and maintaining coastal protection measures can be very costly and may only be achievable when a certain level of wealth is attained" (p. 7).[37]

5. Trends in emissions. Finally, Mr. Shellenberger states in his testimony that "the good news is that the world appears to be headed to temperatures closer to two degrees than four" (p. 6). This is inaccurate; according to the UN Emissions Gap Report discussed in the hearing, current projections are that even if we fully implemented current unconditional Nationally Determined Contributions (NDCs) under the Paris accord, there is a 66 per cent chance that warming could be limited to 3.2°C by the end of the century.[38] Much more aggressive implementation and mitigation could bring these emissions closer in line with a 2-degree temperature increase, but we are not on track to do so and to claim otherwise is inaccurate.

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[34] Hsaing, S. et al. 2017. Estimating economic damage from climate change in the United States. *Science* 356: 1362–1369

[35] Hinkel, J. et al. 2014. Future coastal flood damage and adaptation costs. *Proceedings of the National Academy of Sciences* 111 (9) 3292-3297; DOI:10.1073/pnas.1222469111.

[36] Oppenheimer, M., B.C. Glavovic , et al. 2019. Ch. 4: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, et al. (eds.)]. IPCC

[37] Formetta, G and L. Feyen. 2019. Empirical evidence of declining global vulnerability to climate-related hazards. *Global Environmental Change* 57: 101920.

[38] UNEP (2019). Emissions Gap Report 2019. *Executive summary*. United Nations Environment Programme, Nairobi.

Reponses to Rep. Bera:

a. What work can be done in mitigating the conditions of land degradation, drought, and outdated electrical infrastructure that we know are driving the uptick and high intensity of wildfires in California?

We know that climate change is playing an increasing role in determining wildfire regimes globally, alongside different human activities, with future climate variability expected to enhance the risk and severity of wildfires. We have seen an increase in forest area burned (with higher fuel consumption per unit area) in western and boreal North America in particular. Very large fires are expected to increase in the future in some regions of the US as well, including Northern California.[39] There is strong evidence that in California, the fire season has been extended several months as a result of temperature increases, and extensive drought since 2012 has increased vegetation mortality, adding to fuel loads.[40] Depending on where we are in California, we have both fuel-dominated and wind-dominated fires, which tend to differ somewhat in terms of when they happen, why, and what the potential damages are. However, whether or not any particular fire can be attributed to climate change is more difficult. This is because wildfire occurrence is also moderated by a range of factors including populations and where they are located, land management practices, and ignition sources, which is what has made the California situation so difficult to manage: it is not one single thing that drives these fires. We know that overall increased housing development in the wildlife-urban interface has been demonstrated to increase fire ignitions, for example.[41] As a recent report on the 2017 "Wine Country" wildfires noted, a "vulnerable power system, urbanization of fire-prone areas, flammable invasive species, and poor communication of dangerous conditions contributed to this catastrophic event."[42]

Certainly, tackling California's drought and heat situation through overall global GHG emissions reductions will help ameliorate some of these problems; future projects show that higher emissions scenarios increases the geographic risk of more areas in California subjected to wildfires.[43] Our IPCC Land report shows that better overall forest management – such as retaining soil carbon to hold moisture, avoiding extractive logging practices that are land degrading, and removing or preventing invasive alien species – can all help to promote healthy forests that are more resistant to fires. Better land use planning and zoning that reduces homeowner expansion into the wildland interface – and stricter fire codes and building requirements for structures that do exist in such interfaces, such as enclosed eaves, vent screens, or multi-pane windows – will also likely be necessary.[44] A recent study pointed out that

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[39] Barbero R., et al. (2015). Climate change presents increased potential for very large fires in the contiguous United States. *International Journal of Wildland Fire* 24, 892-899.
[40] Abatzoglou, J.T. & A.P. Williams. (2016). Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences*, 113(42), 11770–11775, doi:10.1073/pnas.1607171113.
[41] Kramer, H., Mockrin, M., Alexandre, P., & Radeloff, V. (2019) High wildfire damage in interface communities in California. *International Journal of Wildland Fire* 28, 641-650.
[42] Mass, C.F. and D. Ovens (2019). The Northern California wildfires of 8–9 October 2017: The role of a major downslope wind event. *Bull. Amer. Meteor. Soc.*, 100, 235–256, https://doi.org/10.1175/BAMS-D-18-0037.1
[43] Westerling, A.L., Bryant, B.P., Preisler, H.K. *et al.* (2011). Climate change and growth scenarios for California wildfire. *Climatic Change* 109, 445–463 https://doi.org/10.1007/s10584-011-0329-9
[44] Syphard, A & Keeley, J. (2019). Factors associated with structure loss in the 2013-2018 California wildfires. *Fire* 2(3): 49 https://doi.org/10.3390/fire2030049

managing California wildfires is about the 5 Ps: *people, prevention, planning, protection* and *prediction*. We need to inform people of fire risks, encourage them to prevent ignitions, plan for placement of homes to put fewer at risk, better protect these homes, and predict when people need to evacuate or utilities need to implement blackouts.[45]

b. What research gaps exist in understanding fire behavior, and what research programs or initiatives might fill these gaps?

In terms of what new research is needed, we certainly need to know more about how we can use controlled fires to prevent worse ones under climate change futures. When fire season risk is extended and these dry and hot conditions increase, that reduces the opportunities to conduct controlled burns, which help prevent more extreme fires.[46] There may be some very useful knowledge embodied in indigenous fire burning practices that can be helpful in managing these types of controlled burns as well.[47]

We need more information about tipping points in fire regimes; that is, when repeated fires cause a shift in vegetation from a forested state to an alternative state such as a grassland. Invasive alien species are likely to be part of this mix of drivers. For California in particular, there is uncertainty about how ecosystems such as the semiarid inland deserts and coastal areas of the south will respond to future fire activity and in what ways, and the role of degradation feedbacks are particularly important to study in these areas.[48] We also need to know more about the carbon releases from these extreme fires; some estimations are the California wildfires in Oct 2017 increased atmospheric C concentrations by 2 ppm.[49]

Prediction capabilities for fires also need to improve. It's not just a matter of biophysical parameters though, as we need to better predict when humans may ignite fires, and where the biggest anthropogenic influences on fire risks are.[50] Better predictive analytics using AI, for example, may help us determine wildfire risks and safety issues in the future, and investments in this area would be very welcome.

c. What are the biggest obstacles to reducing the risk of future fires? What can Congress do to encourage the adoption of practices or technologies to mitigate fire risk?

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[45] Keeley, J. & Syphard, A. (2019) Twenty-first century California, USA, wildfires: fuel-dominated vs. wind-dominated fires. *fire ecol* 15, 24 https://doi.org/10.1186/s42408-019-0041-0

[46] Olsson, L., H. Barbosa, et al., 2019. Ch. 4: Land Degradation. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, et al. eds]. Geneva: IPCC.

[47] R.W. Kimmerer, & F.K. Lake (2001). The role of Indigenous burning in land management. *Journal of Forestry*, 99(11) : 36–41, https://doi.org/10.1093/jof/99.11.36

[48] Olsson, L., H. Barbosa, et al., (2019) ibid.

[49] Li, A., Wang, Y., & Yung, Y. (2019). Inducing factors and impacts of the October 2017 California Wildfires. *Earth and Space Science* 6, 1480– 1488. https://doi.org/10.1029/2019EA000661

[50] Mann ML, et al. (2016). Incorporating anthropogenic influences into fire probability models: Effects of human activity and climate change on fire activity in California. *PLoS ONE* 11(4): e0153589. https://doi.org/10.1371/journal.pone.0153589

The California situation is complex, particularly around utility-started fires, which are associated with Santa Ana wind conditions, which are nearly impossible to control: in other words, the "conditions that cause power lines to start wildfires are the exact same conditions that make them spread rapidly and make them hard to contain."[51] Debates over policies for utilities, such as inverse condemnation liability, are likely to have to been rethought, especially if risk increases in the future not due to negligence, but due to the increasing frequency of fire conditions and extended fire seasons. Expanded wildfire preparedness and thinking about how to encourage resilient infrastructure planning at the federal level would help not only California but other states deal with the increasing risks to their transport networks, utilities and other infrastructure.[52] Given the costs associated with moving electrical wires underground, federal assistance is likely going to be needed for this; priorities could be made by focusing the need for burying powerlines in precisely those places where Santa Ana winds whip through corridors and have sparked the recent fires. There is also the potential to install weather stations on poles in the most at-risk areas that could continuously monitor risk conditions, and automatically shut down areas in the grid that are experiencing the most severe winds during fire season conditions.[53]

[51] Kausky, C. et al. (2018). Wildfire costs in California: The role of electric utilities. Wharton Risk Management and Decisions Processing Center Issue Brief. Philadelphia: University of Pennsylvania.
[52] Hill, A. and W. Kakenmaster, (2020). Resilient infrastructure: Understanding interconnectedness and long-term risk, in *Optimizing Community Infrastructure*, Ryan Colker, ed. Butterworth-Heinemann, pp. 5-21.
[53] Keeley and Syphard (2019), ibid.

Responses by Dr. Richard Murray

House Committee on Science, Space, and Technology
"An update on the climate crisis: From science to solutions"
Questions for the Record

Response from Dr. Richard Murray
Woods Hole Oceanographic Institution

Is there anything else you would like to address that you did not get a chance to during the hearing?

Chairwoman Johnson: Thank you for the opportunity to follow up on my testimony and replies to questions at the hearing. The most significant point I would like to reiterate is the critical need for a significant commitment and investment in the federal Earth system observation, monitoring and modeling enterprise. The SROCC report documents the rapid rate of change in numerous processes that will have direct impacts on the economic welfare, security, and health of individuals in the U.S. and across the world. I would argue that the ocean is the least observed of Earth systems, and quite possibly the most important given its role as major heat (90 percent) and carbon (25-30 percent) sink and distribution mechanism.

The existing U.S. ocean and coastal observing, monitoring and modeling enterprise, while significantly greater than it was a decade ago, remains woefully inadequate to provide the quantity and quality of information, with a high level of confidence, required to inform decision makers faced with difficult policy and fiscal challenges. This situation is highlighted by the essentially flat funding over the past decade for ocean and coastal observations provided to NOAA, who is responsible for civilian operational oceanography. While significant attention and investment has gone into NOAA's atmospheric enterprise, including satellite acquisition exceeding $10 billion, attention and resources for its ocean-focused enterprise has languished. NOAA is not the sole civilian federal agency with ocean and coastal responsibilities. NSF, NASA, BOEM, USACE, DOI, DOE, and DHS and others all make key contributions, and will also need to increase their support. However, it is critical that Congress recognize NOAA is the lead federal agency responsible for oceans and coasts and the agency will require considerably greater resources to fulfill its mandates, with one of the primary roles being the collection, synthesis, management of data that can be ingested into models and other predictive tools, for use by other federal agencies, state, academia and the private sector. Below are links to a few articles that emphasis the need for a significantly enhanced ocean and coastal observations and modeling in order to advance the larger Earth science enterprise.

Thankfully, the importance of enhancing the Earth observation enterprise is also recognized by the current Administration, who's Fiscal Year 2021 Research and Development funding priorities, as outlined in the OMB and OSTP memo (https://www.whitehouse.gov/wp-content/uploads/2019/08/FY-21-RD-Budget-Priorities.pdf), specifically highlights the importance of Earth system predictability, stating that: "Knowing the extent to which components of the Earth system are practicably predictable - from individual thunderstorms to long-term global change - is vitally important for physical understanding of the Earth system, assessing the value of prediction results, guiding Federal investments, developing effective policy, and improving predictive skill. Departments and agencies should prioritize R&D that helps quantify Earth system predictability across multiple phenomena, time, and space scales." The commonality of interest hopefully is putting us on the path towards a more robust observing system.

Ocean Twilight Zone

I also want to highlight a major philanthropically funded 5-year research program being led by WHOI studying the ocean twilight zone (https://twilightzone.whoi.edu), an area that has been virtually unexplored and unobserved until now, and which plays a major role in ocean biological processes, including the cycling of carbon dioxide.

The ocean twilight zone—a biologically rich swath from 200 to 1,000 meters below the surface—plays a critical role in the ocean's biological carbon pump and long-term carbon storage. Biological processes in the twilight zone contribute to sequestering an estimated 2 to 6 billion metric tons of carbon annually—at least double and perhaps as much as six times the amount of carbon emitted by all automobiles worldwide. At a conservative carbon price of $35 to $45 per ton of carbon dioxide, this regulating service can be valued at $300 to $900 billion each year. Without this service, atmospheric carbon dioxide levels could be as much as 200 ppm higher than they are today. The value of such a loss in sequestration service could amount to between $170 billion and $3 trillion in mitigation costs and $23 to $401 billion in adaptation costs by the end of the century.

Concern surrounds the potential commercial harvests of twilight zone crustaceans and fish given uncertainty how it may inhibit the functions of this biological carbon pump in some locations and during some seasons. In addition, increased greenhouse gas emissions could lead to thermal stratification and declining pH (acidification) that might limit the transport of carbon from the atmosphere through the twilight zone to the deep ocean.

Our understanding of the ocean twilight zone and its role as a major biological carbon pump is one of the major new areas of research, but the continuation of this work will require leadership and support from NOAA and other federal science agencies.

I will conclude by providing links to a few articles that help to highlight the importance of ocean observing, monitoring and modeling to our understand of ocean and coast process, and the land-sea-air dynamic coupling that drives natural and anthropocentric climate change.

Climate Change: Ocean Heat Content
https://www.climate.gov/news-features/understanding-climate/climate-change-ocean-heat-content
Rising amounts of greenhouse gases are preventing heat radiated from Earth's surface from escaping into space as freely as it used to. Most of the excess atmospheric heat is passed back to the ocean. As a result, upper ocean heat content has increased significantly over the past two decades.

Ocean Climate Observing Requirements in Support of Climate Research and Climate Information
https://www.frontiersin.org/articles/10.3389/fmars.2019.00444/full
Understanding and monitoring ocean climate variability and change, to constrain and initialize models as well as identify model biases for improved climate hindcasting and prediction, requires a scale-sensitive, and long-term observing system.

Industrial-ear decline in subarctic Atlantic productivity
https://www.nature.com/articles/s41586-019-1181-8
Using a continuous, multi-century record of subarctic Atlantic marine productivity, we show that a marked 10 ± 7% decline in net primary productivity has occurred across this highly productive ocean basin over the past two centuries.

Understanding Sea Level Rise
https://www.whoi.edu/wp-content/uploads/2019/11/File-name-01474-Sea-Level-Rise-Report-final-with-DOI.pdf?_ga=2.30230779.516602569.1584122636-803310036.1584122636

Since the turn of the 20th century, the seas have risen between six and eight inches globally. New technologies, along with a better understanding of how the oceans, ice sheets, and other components of the climate system interact, have helped scientists identify the factors that contribute to sea level rise.

A New Age of Exploration
https://www.whoi.edu/multimedia/otz-earths-final-frontier/
What was once thought to be adesert-like isn't a desert at all. Where deep sea creatures lurk there are incredible biomass and biodiversity. The ocean Twilight Zone is a huge habitat that is very difficult to explore.

Responses by Dr. Heidi Steltzer

Heidi Steltzer, PhD
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April 15, 2020

The Honorable Eddie Bernice Johnson and the Honorable Frank Lucas,

Thank you for this opportunity to answer several additional questions from the Climate Crisis hearing on January 15, 2020 for the record. My answers to the questions are below.

1. **Is there anything else that you would like to address that you did not get a chance to during the hearing?**

I've been re-reading my oral testimony, since learning of the pandemic. There are striking parallels between the recommendations I provided in January to address the climate crisis and what will support American recovery during and after a pandemic. We should aim to be a resilient nation, a good neighbor, and work together to write new narratives about the environmental issues our country faces – narratives that unite rather than those that currently divide. I left the hearing on January 15, 2020 hopeful.

I remain hopeful today amidst this pandemic, despite news that individual and government choices that disregard science have led to the greatest number of confirmed COVID-19 cases in the US, currently over a half million. We are also the first nation to record more than 2,000 deaths in a day. This should not be. We are not the most populous nation, nor do we lack public and private wealth to invest in the health of our nation. The US economy depends on the health of everyone for whom America is home.

I stay hopeful about what we can do to invest in a future that is different than the present. There will always be reasons to invest in new scientific discoveries that can only be possible through US government funding for an icebreaker, a novel nuclear reactor or more nuclear reactors, or better atmospheric and watershed models. Let's begin to pair these well-established and fundamental aspects of science with equal investment in initiatives that foster trust in science, improve science education, and value local science.

Local science is a makerspace turned personal protective equipment factory to supply a local hospital. Local science is the science outside and down the street or up the hill, or in my case mountain, that can take place when scientists work and live in the region they study. Funding science at rural institutions will grow local science. This could include providing funds to the rural institutions and incentivizing well-funded institutions, federal agencies, foundations and businesses to partner with rural institutions. This could be to establish college/university-affiliated field stations and centers for mountain, desert, forest, river or coastal science at rural institutions. Rural institutions are a hub for science in regions of ecological riches that are the wealth of our nation.

In numerous articles, the media has touted that COVID-19 is putting global change science 'on hold'. These articles state that critical environmental data sets to characterize the impacts of climate and other environmental changes may not be collected this year. However, that field science stalls greatly due to COVID-19 is indicative that established systems of funding science do not necessitate or reward local science.

US global change research in Greenland or Alaska would not stall if research programs had been developed in collaboration with the local communities. Furthermore, the insights gained would include the perspectives of people who best know how these regions have changed and how to adapt to the changes. Though less remote, a similar case can be made for mountains and prairies, rivers and coasts across the continental US. The open ocean and Antarctica, places without local communities, are exceptions that highlight the need for remote monitoring approaches, including durable sensors and low cost sensor networks to ensure necessary data are collected.

To reduce the harm from environmental changes, scientists recommend that people adapt, changing practices and policies. Scientists and the systems for funding and awards must also adapt. Rather than sustaining research during the current pandemic, we need to plan for ways to adapt global change science. For adaptation, far more funding than in the past should be invested in programs, fellowships, and awards for rural institutions and local scientists.

1. We know that increased warm weather caused by climate change will cause more winter precipitation to fall as rain. This will create thinner snowpack leading to more runoff water earlier in the season. In the 2019 Intergovernmental Panel on Climate Change Special Report on the Oceans and Cryosphere chapter on High Mountain Areas, for which you were the lead author, it is noted that for California and the Southwestern USA, a shift to peak snowmelt earlier in the year would lead to economic losses estimated at 10.8-48.6 billion USD by around 2050. In addition, we know that our current water storage and conveyance system in California needs to be modernized to adjust to the changing period of peak snowmelt.
    a. In the above illustrated scenario, what would be the primary industries affected by this change in peak snowmelt and what needs to be done to preserve snowpack and runoff in ways that will support said industries?

Agriculture will be affected, because the rate of warming doesn't shift the timing for planting and crop growth to the same extent that peak snowmelt is shifting due to less snow, dust on snow and warmer temperatures. Thus, the water from melting snow will have moved via rivers to the sea prior to when plants in agricultural systems are ready to harvest. For this, there will need to be systems to store water, which have traditionally been reservoirs on the surface. Existing reservoirs have lost water due to climate warming driving greater evaporation over past decades. This suggests that where/if possible belowground water storage systems might be better. The naturally-occurring, belowground water storage system is when melting snow flows to groundwater. Much remains to be understood about the sensitivity of groundwater supply to climate change impacts on mountain snowpack. Further studies into this area are underway by the US Department of Energy, including in the research team of which I'm a part. Adaptation through selecting new regions to farm/ranch, new crops that require less water or can be planted earlier and practices for restorative agriculture, which can improve plant water use efficiency, are all also practices that could decrease the impact of earlier snowmelt on agriculture and food supply.

Winter tourism and recreation industries already are affected by earlier peak snowmelt in California, Colorado and elsewhere across the US. Snow during ski season is less reliable and often less. Later onset of snowfall and earlier snowmelt shrink the duration of the ski season. Snowmaking in resorts is a short term solution, but has impacts on water supply and river health. Developing alternative recreational opportunities is another way the winter tourism and recreation industries could adapt. Are there new ways people can enjoy mountain regions when it is cold and there isn't snow and when it is cold and there is less snow? For me, the answer is yes – cold hikes on trails not yet covered by snow in November and December are extraordinary though I recognize there may be a limited number of people who would agree. In my family, we often talk about how there is no such thing as bad weather. We adapt what we wear and what we do to enjoy nature in all its variedness. Thus, it may be a cultural change that is needed, one that can be developed in collaboration with the outdoor retail industry to ensure people can afford and like the opportunities changing snow creates for winter tourism and recreation.

Industries that depend on energy supply from hydropower would also be affected by shifting timing and availability of hydropower supply. I'm not sure what these would be, but expect it could affect materials production, such as steel and concrete for building, and/or other energy intensive industries. Changing the resources needed to less energy intensive ones or the energy system to wind or solar could reduce impacts.

1. **How fast are impacts on the Arctic and cryosphere moving relative to model predictions and in your view, how close are we to dangerous tipping points?**

2. **Do the risks of abrupt change—such as the collapse of the West Antarctic Ice Sheet, which would cause catastrophic sea level rise—indicate that we should think seriously about technological interventions such as reflecting sunlight from the atmosphere to maintain stability?**

We should expect the unexpected, both for tipping points of which we know and ones about which we don't yet know. Most months, I read an article that informs of faster losses of Arctic methane than expected from models and known processes, of how the loss of snow affects energy exchange between the land and sky, decreasing water supply in the Western US, of larger losses from unstable Ice Sheets than was thought possible until mid- to late- 21st Century, or of regions of Antarctica where Ice Sheets were considered stable losing ice. It's generally one peer-reviewed scientific article per month that reveals to me a new event, a new process, a different rate of change than what has been expected. I read a fair bit, but expect I'm missing many new findings.

We should be cautious about introducing a cryosphere-equivalent of mongoose to Hawaii or rabbits to Australia – we can't know all that will happen if we chose to reflect sunlight to space or add iron to the Southern Ocean. As a scientist, I've learned to value and learn from the many results that are different than I expect, to explore what led to them, and to be ever cautious in proposing a solution to an environmental issue that can't be tested and thereby increases risk despite the laudable aim of protecting people.

Cutting carbon emissions, planting trees and grasses, and conserving the lands and seas that store carbon are all more practical and assured solutions to climate change than reflecting sunlight to space. They also provide an immense number of other benefits including reducing air pollution and the spread of infectious disease. There is a strong link between land use change, human development and the increasing local to global risk of diseases spilling over from animals to people, such as for lyme disease, ebola and COVID-19.

For scientists who have long-studied environmental issues, it is not surprising that the environment is currently having a disastrous effect on human well-being. We've known for some time that a human pandemic or agricultural pest, water shortage or heat wave, megafire or terrible storm would occur, and that our past and present choices would affect the scale and magnitude of the disaster. Though scientists provide these insights, public understanding and policy do not reflect what scientists already know. Many Americans distrust scientists and therefore disregard science at their own peril, and tragically at the peril of their children.

Rather than defining the problem and impacts better, I encourage focusing on resilience, ecological and economic recovery, and fostering trust in science. Prominence in science should be coupled to how scientists engage with society, because trust in science depends on people knowing scientists.

Many of my neighbors in rural Colorado watched for the first time ever a US Congressional hearing, because they knew me. Every American can know a scientist. This is what is needed for people to value science in America. This is what is needed for America to be a resilient nation and a good neighbor in an era of global environmental changes.

Best wishes,

Heidi Steltzer, PhD
Mountain Scientist
Professor Environment and Sustainability
Fort Lewis College

Responses by Mr. Michael Shellenberger

Please refer back to my testimony.

Responses by Ms. Taryn Fransen

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Responses to Questions for the Record to Taryn Fransen
February 18, 2020

The following document draws on research and analysis by the World Resources Institute and others to address the Questions for the Record submitted to Taryn Fransen by House Science Committee Chairwoman Eddie Bernice Johnson on February 3, 2020.

QUESTION 1 | **What are the most urgent mitigation and adaptation needs, and what are the greatest barriers to achieving these goals?**

The IPCC Special Report on 1.5°C is clear that major and immediate transformations across all sectors of the economy will be required to limit global warming.[1] In the United States, this means transforming the following sectors to reduce emissions and address existing barriers:

Transportation
Transportation is now the largest source of greenhouse gas emissions in the United States. A comprehensive set of policies addressing vehicles, fuels, infrastructure, and mobility options will be needed to eliminate pollution from this sector while improving Americans' quality of life. Passenger vehicles are typically on the road for more than 10 years, so all new passenger vehicles would have to have zero emissions by about 2035 to achieve a near-zero emission fleet by 2050, unless programs are later adopted to drive early retirement of combustion powered cars or fuels are decarbonized. For the near term, Congress should prevent EPA from undermining the vehicle standards established in 2012 with the agreement of the automobile industry and could consider mandating standards consistent with the agreement that California reached with Ford, Honda, VW, and BMW. For the period from 2026 through 2035 Congress should consider adopting a mandate that EPA set standards that progressively reduce allowable emissions from new cars to zero. Such standards should ensure continued improvements to internal combustion engine vehicles as well as increases in the market share of zero-emission vehicles.

Long-haul trucking and aviation are expected to be more challenging components of the transportation system to decarbonize. Congress could help support the transition for these transportation modes by increasing funding for development, demonstration, and testing of electric and hydrogen fuel cell Class 8 trucks, as well as a variety of zero-emission aviation concepts. At the same time, a focus on improving transportation infrastructure will be essential to mitigate climate risks. Climate change is already impacting this infrastructure through higher

[1] IPCC, "Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (Eds.)].," 2018.

temperatures, more severe storms and flooding, and higher storm surges, affecting the reliability and capacity of the nation's transportation systems.

Power

Electricity production is the second largest source of greenhouse gas emissions in the United States. Rapid decarbonization of the electricity sector is critical for addressing the climate crisis. While recent years have seen record renewable deployment, the literature suggests that we still need to dramatically increase the rate at which the country is deploying zero-carbon generation in order to address climate change. A range of policies and programs could help, including: a carbon price, a clean energy standard, clean energy tax credits, improved electricity market regulations, policies that support an expansion of high-voltage transmission, and policies that support maintaining existing nuclear plants that are deemed safe to operate. In addition, continued research, development and deployment of new technologies and practices is warranted. This includes short and long-term electricity storage, demand response, electrolysis to create hydrogen fuel, and carbon capture and storage.

Industry

Industry is responsible for 22 percent of greenhouse gas emissions in the United States,[2] and important segments of the sector remain emissions-intensive. Congress could help US industry reduce emissions and enhance its competitiveness in the global marketplace by expanding R&D for new, innovative industrial technologies. In addition, Congress could leverage the considerable buying power of the federal government to support investment in low- and zero-carbon products, such as those on the market today for cement and steel. In addition, Congress could direct EPA to develop an Advanced Notice of Proposed Rulemaking that examines opportunities for reducing emissions from large industrial sectors, including cement, steel, and petrochemical facilities [3]

Buildings

Buildings account for over one-third of greenhouse gas emissions in the United States.[4] In order to decarbonize them, steps must be taken to boost the energy efficiency of appliances and of the building envelope itself. Buildings will also need to be powered by zero-carbon sources of energy, though electrification and other measures. The good news is that these measures can save households and businesses money. According to U.S. DOE, building energy codes will save U.S. home and business owners an estimated $126 billion and 841 million metric tons of avoided carbon dioxide emissions from 2010 through 2040.[5]

Congress could support continued progress by directing DOE to update the model federal building codes and providing assistance and incentives to encourage states to update their own standards.

National energy efficiency standards for more than 60 appliances and products represent about 90 percent of home energy use, 60 percent of commercial building energy use, and 30 percent of industrial energy use. The

[2] Including the industry sector's share of emissions from power generation, addressed above
[3] https://www.arb.ca.gov/lists/com-attach/1-cn-and-industry-ws-Uj5UPVIkWVUEYQlo.pdf
[4] Including the building sector's share of emissions from power generation, addressed above
[5] https://www.energycodes.gov/about/results

standards currently in place save the average household approximately $500 on energy bills annually[6], and are expected to save 70 quadrillion Btu (quads) of energy by 2020 and 132 quads through 2030, equivalent to more than a year's worth of energy consumption for the entire country.[7] Unfortunately, as of January 2020, the Department of Energy has missed deadlines for updating standards for 21 products.[8] In addition to oversight pressure from Congress, Congress could allow states to adopt their own standards if the DOE fails to update standards within a reasonable timeframe.[9] Congress could also take steps to prevent the administration's rollback of efficiency standards for new lightbulbs.[10]

In addition to codes and standards, Congress can continue to use fiscal approaches and financial incentives to encourage faster adoption of buildings-related measures and provide assistance and recognition to celebrate and encourage leadership and early adopters.[11]

Agriculture and Forests

Forests currently offset 11 percent of U.S. greenhouse gas emissions, but their rate of carbon sequestration is projected to decline as they age and as fragmentation increases. Restoring trees to the American landscape through reforestation, restocking timberlands, silvopasture, cropland agroforestry, and urban reforestation could remove as much as an additional half a gigaton of CO_2 from the atmosphere per year through 2050 without displacing agricultural production. The primary barrier to tree restoration is the high upfront costs on private lands, where most of the potential is located. Although total economic benefits of tree restoration exceed total costs when fully accounting for public benefits like clean water, flood protection, and carbon sequestration, few of those benefits accrue directly back to landowners. The financial barriers to tree restoration could be addressed via with public subsidies, which would need to amount to $4-4.5 billion per year to capture the full potential for tree restoration over a 20-year period.

Agriculture is responsible for 9 percent of greenhouse gas emissions in the United States. Many mitigation strategies exist in agriculture that can bring about other benefits too. For example, soil management practices such as cover cropping and compost amendment can promote soil health and provide incremental carbon sequestration, while technologies like precision agriculture can reduce emissions from fertilizer use while boosting farm profitability. Many novel agricultural practices and technologies are subject to significant uncertainty regarding their net impacts on greenhouse gas emissions and agricultural yields, however, which hinders their widespread adoption across agricultural lands in the United States. Producers may also lack the

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[6] https://appliance-standards.org/sites/default/files/Fact%20Sheet_Why%20National%20Appliance%20Standards%20Mar%202017.pdf

[7] https://appliance-standards.org/sites/default/files/Next%20Gen%20Report%20Final_1.pdf

[8] Andrew deLaski, "Trouble Ahead for US Appliance Efficiency Standards," Appliance Standards Awareness Project, January 24, 2020.

[9] While in theory, this proposal could result in a large number of standards for any particular product, in practice it is likely that states would coordinate with each other. Concerns arising from the existence of multiple state standards can be further addressed by establishing ways for limiting the number of different thresholds states could impose at any particular time.

[10] NRDC Press Release, "Trump Administration Defies 2007 Law & Ties Americans to Energy-Wasting Bulbs," Natural Resources Defense Council, December 20, 2019.

[11] https://www.wri.org/publication/international-efforts-increase-energy-efficiency-opportunities-advance-energy-united-states

capacity or infrastructure to implement new practices properly on their fields. An on-farm research and innovation program that provides financial and technical assistance to producers experimenting with new, carbon-friendly practices and technologies could begin to address these barriers. The program would need to include 10 million acres to enable researchers to draw robust inferences about practice efficacy that could advance scientific understanding of mitigation opportunities in agriculture. Sustaining such a program would require annual federal funding on the order of $500 million.

Adaptation

While some of the above mitigation strategies can bring about adaptation benefits, Congress will also need to provide targeted assistance to help communities become more resilient in response to climate change. Current and future climate impacts threaten the US economy and infrastructure and will continue to devastate human and social welfare – particularly in underserved and marginalized communities. There is a clear economic and moral imperative for Congress to urgently enact policies that can help ensure that federal resources are used wisely, and that government operations and services remain functional and effective in a changing climate. Congress could support improved climate resilience by:

- Encouraging federal agencies to modernize their programs to support climate resilient investment.
- Underscoring and resourcing the critical role that federal agencies play in providing information, data and tools for climate change preparedness and resilience.
- Requiring all agencies to develop, implement and update comprehensive plans that integrate climate preparedness and resilience into agency operations and overall mission objectives – avoiding a siloed effort – and to report on progress against these plans.
- Incentivizing up-front investments in preparedness and resilience to protect vital infrastructure as well as ensure that vulnerable communities have the resources and capacity to adapt.
- Changing building and design standards so that post-disaster, we build back stronger and better.
- Recognizing that some communities in high-risk areas may need relocation grants, and communities receiving new residents may also need financial resources.

Suggested resources:

- Seeing is Believing: Creating a New Climate Economy in the United States[12]
- Adapt Now: A Global Call for Leadership on Climate Resilience[13]
- RELEASE: Global Leaders Call for Urgent Action on Climate Adaptation; Commission Finds Adaptation Can Deliver $7.1 Trillion in Benefits[14]
- International Efforts to Increase Energy Efficiency and Opportunities to Advance Energy in the United States: Testimony of Jennifer Layke, Global Director for Energy, World Resources Institute[15]
- CarbonShot: Federal Policy Options for Carbon Removal in the United States[16]

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[12] https://www.wri.org/publication/seeing-believing-creating-new-climate-economy-united-states
[13] https://cdn.gca.org/assets/2019-09/GlobalCommission_Report_FINAL.pdf
[14] https://www.wri.org/news/2019/09/release-global-leaders-call-urgent-action-climate-adaptation-commission-finds
[15] https://www.wri.org/publication/international-efforts-increase-energy-efficiency-opportunities-advance-energy-united-states
[16] https://www.wri.org/publication/carbonshot-federal-policy-options-for-carbon-removal-in-the-united-states

QUESTIONS 2 AND 3 | **What investments should this Committee be making in federal research and development efforts in the immediate future to further develop and implement effective mitigation and adaptation strategies? On what scale should these investments be made?**

Addressing the climate challenge requires a sustained commitment to research, development, and deployment (RD&D) for mitigation and carbon removal. Public investment is needed to increase the pipeline of technologies that have the potential to be commercially competitive at scale.

Through consultation with a variety of experts, WRI developed a detailed, priority RD&D list for mitigation technologies attached as the appendix to this document.[17] The list identifies recommended increases for RD&D above FY19 levels for technologies in the following categories:

- Power sector - $435 million
- Transportation - $175 million
- Buildings and industrial processes - $95 million
- Enabling and other technologies - $240 million

The National Academies of Sciences identified federal research and development requirements to spur innovation in carbon removal. WRI summarizes some of the most important of these recommendations in Wanted: $325 Million for Federal R&D to Jumpstart Carbon Removal.[18] This includes:

- $10-15 million per year for a national on-farm soil monitoring system and an experimental soil carbon field network
- $40-50 million per year to breed plants that store more carbon
- $25 million per year to tackle economic, social and environmental questions surrounding the use of biomass for energy
- $75 million per year for research, development and demonstration to drive down the cost of direct air capture technology
- $35 million per year to advance scientific understanding of technological mineralization processes
- $125 million per year to improve capabilities for storing captured carbon underground, safely and effectively

Notably, Congress took a promising step forward on these recommendations in late 2019 by appropriating at least $25 million for research and development of direct air capture technology and $60 million overall for research into a broader set of carbon dioxide removal technologies.

[17] These recommendations have also been provided as a World Resources Institute submission to the House Select Committee on the Climate Crisis on November 22, 2019.
[18] https://www.wri.org/blog/2018/12/wanted-325-million-federal-rd-jumpstart-carbon-removal

QUESTION 4 | **How do new climate change scenarios developed by the International Energy Agency compare to scenarios evaluated by the Intergovernmental Panel on Climate Change, and what do they imply for current projections on global temperature rise?**

Figure 1 and Table 1 present 2030, 2040, and 2050 CO_2 emissions from the 2019 International Energy Agency World Energy Outlook scenarios relative to the IPCC scenarios aligning with different 1.5°C and 2°C temperature outcomes. The IEA WEO Current Policy Scenario and Stated Policy Scenario, which reflect pathways under existing (Current) and existing and planned (Stated) policies and measures as of mid-2019, contain CO_2 values well above the IPCC "higher 2°C" scenarios. This is broadly consistent with the finding of the 2019 *UNEP Emissions Gap Report* that current commitments and policies suggest 3 to 3.5°C of warming. The IEA WEO Sustainable Development Scenario, which by design reflects a scenario under which the world takes effective action to combat climate change, is in the range of the IPCC scenarios that limit warming to below 2°C.

Figure 1 | Comparison of IPCC Special Report on Global Warming of 1.5°C and IEA WEO scenarios

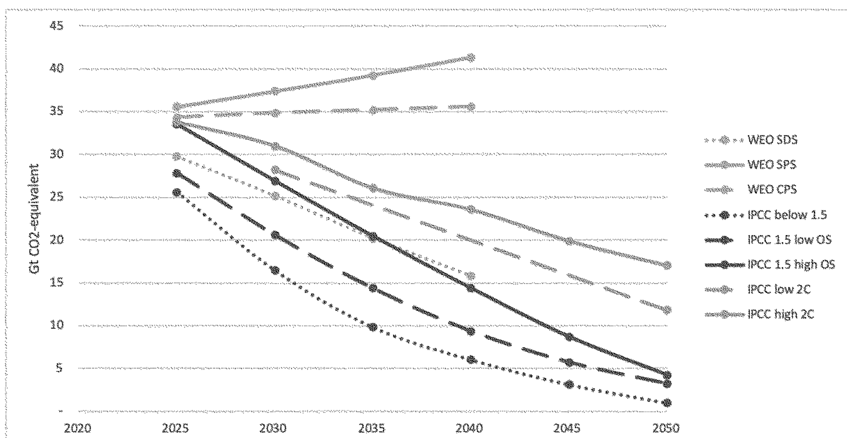


Table 1 | CO_2 emissions in IEA and IPCC scenarios ($GtCO_2$/year)[19]

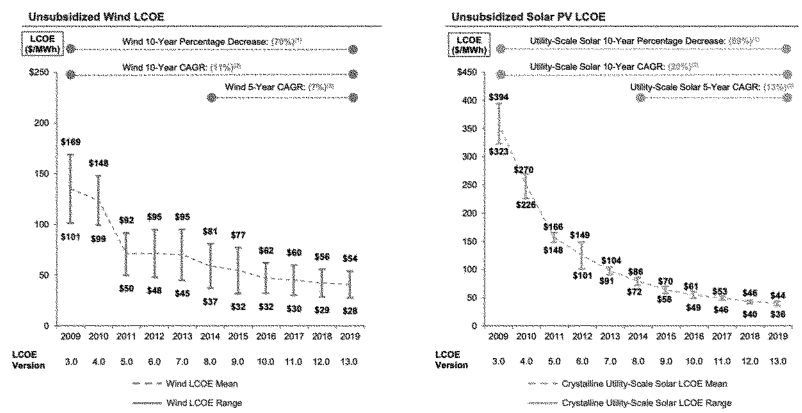
Scenario	Scenario Description	2030	2040	2050
IEA WEO Current Policy Scenario	Includes the effects of only those government policies and measures that had been enacted or adopted by mid-2019 and assumes those continue unchanged. Provides a baseline that shows how global energy markets would evolve without any new policy intervention.	37.4	41.3	N/A
IEA WEO Stated Policy Scenario	Reflects the impact of policies and measures that are in effect or adopted as of mid-2019, together with announced policy intentions that are yet to be formally adopted. Provides a benchmark to assess the potential achievements (and limitations) of recent developments in energy and climate policy.	34.9	35.6	N/A
IPCC Higher 2°C	Pathways assessed to keep peak warming to below 2°C during the entire 21st century with 50–66% likelihood.	31.0	23.5	17.0
IPCC Lower 2°C	Pathways limiting peak warming to below 2°C during the entire 21st century with greater than 66% likelihood.	28.2	N/A	11.8
IPCC 1.5°C High Overshoot	Pathways limiting median warming to below 1.5°C in 2100 and with a greater than 67% probability of temporarily overshooting that level earlier, generally implying 0.1–0.4°C higher peak warming than Below-1.5°C pathways.	26.9	14.4	4.2
IEA WEO Sustainable Development Scenario	An integrated scenario specifying a pathway aiming at: ensuring universal access to affordable, reliable, sustainable and modern energy services by 2030 (SDG 7); substantially reducing air pollution (SDG 3.9); and taking effective action to combat climate change (SDG 13). Holds the temperature rise to below 1.8 °C with a 66% probability without reliance on global net-negative CO_2 emissions.	25.2	15.8	N/A
IPCC 1.5°C Low Overshoot	Pathways limiting median warming to below 1.5°C in 2100 and with a 50–67% probability of temporarily overshooting that level earlier, generally implying less than 0.1°C higher peak warming than Below-1.5°C pathways.	20.6	9.3	3.2
IPCC Below 1.5°C	Pathways limiting peak warming to below 1.5°C during the entire 21st century with 50–66% likelihood.	16.4	6.0	1.0

[19] The IPCC scenarios presented are the median number across all the scenarios in each of the five pathway classes used in IPCC Special Report on Global Warming of 1.5°C (SR15). There are 90 scenarios covered in 1.5°C or 1.5°C consistent classes (Below 1.5°C, 1.5°C Low Overshoot and 2°C High Overshoot), and 132 scenarios in the 2°C or 2°C consistent classes (Lower 2°C and Higher 2°C). Emissions from variable "CO_2 from fossil fuels and industry (net)" are presented here among the ones presented in Table 2.4 of the SR15 report as those are most comparable with the WEO scenarios, which cover CO_2 emissions from fossil fuel combustion.

QUESTION 5 | **To what extent do variability, cost, and land-use requirements pose prohibitive constraints on the expansion of renewable energy resources in the United States?**

Achieving a 100 percent zero-carbon energy mix is foundational to any credible strategy to address climate change. In theory, a variety of combinations of resources and technologies – including renewable energy, nuclear, and fossil fuel combined with carbon capture and storage – could achieve this outcome. With the costs of renewable energy falling rapidly, however, most "deep decarbonization" analyses envision that by mid-century, renewables will make up by far the largest share of power generation in the United States.[20] The levelized costs of new wind and solar generation have plummeted over the past decade (Figure 2) and are now competitive with the marginal cost of existing generation sources such as coal and nuclear (Figure 3).

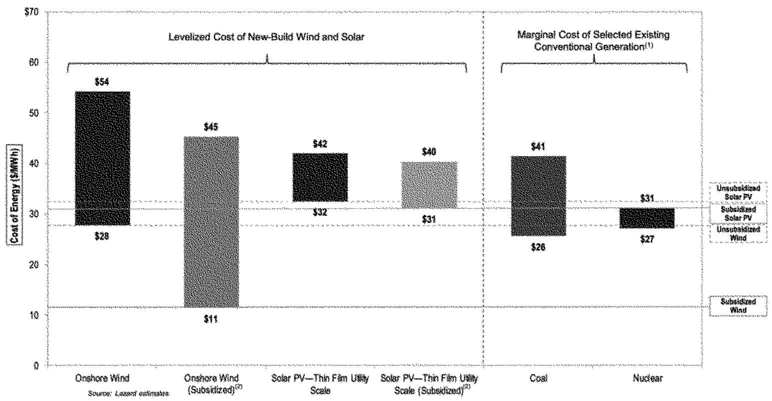
Figure 2 | Levelized Cost of Energy for Wind and Solar PV, 2009-2019



Source: https://www.lazard.com/perspective/lcoe2019

[20] For example, see *United States Mid-Century Strategy for Deep Decarbonization* (November 2016) and Cleetus et al., *US Power Sector in a Net Zero World* (2016).

Figure 3 | Levelized Cost of New Wind and Solar Compared to Marginal Cost of Conventional Generation



Source: https://www.lazard.com/perspective/lcoe2019

Levelized cost of energy is an important metric, but it does not take into account other generation characteristics, such as variability. While some renewable energy resources, such as geothermal and biomass plants, share dispatchable or baseload characteristics with fossil fuel resources such as natural gas, solar and wind energy are characterized by natural and largely predictable variation in availability. Power systems are designed to manage some degree of variability and uncertainty. For instance, electricity demand is both variable and uncertain across all timescales, and even baseload generation can suffer unpredicted failures.

As increasing shares of variable renewable resources are added to the grid, power systems operators can take advantage of a growing suite of tools to manage the additional variability.[21] These tools range from low- or even negative-cost measures such as improved forecasting and faster system operations to higher-cost, more cutting-edge options such as battery energy storage. These tools are well understood and are increasingly becoming core components of integrated resource planning as utilities anticipate higher levels of variable renewable energy. Large power systems such as those in Texas, California, and the eight states within the service territory of Xcel Energy are deploying these practices and are now each meeting over 20 percent of their annual electricity demand with solar and wind energy while planning further growth in solar and wind energy deployment.

With regard to land requirements, a detailed assessment of the land-use implications of different scenarios for decarbonizing California's electricity sector found that direct land footprints are comparable across most scenarios, including those that rely more heavily on renewable generation and those that rely more on other

[21] https://www.nrel.gov/docs/fy15osti/63039.pdf

sources, such as nuclear. While the footprint of renewable generation is initially higher, the footprints of fossil and nuclear generation increase over time as fuel use continues.[22] Nevertheless, care is warranted in siting solar and wind projects – as it would be in siting any form energy infrastructure – to avoid conflict with other land-use priorities, and to take advantage of complementarity with other land uses. For instance, wind companies are already paying farmers and other rural landowners over $220 million per year to host wind turbines.[23] Promising pilot projects are also underway in Massachusetts, Arizona, and internationally to mix crop production with solar generation.[24] Finally, residential rooftop solar PV, which has negligible land-use impacts, is growing rapidly and has reached over 10 percent of single-family detached homes in some states.[25]

With only 17 percent of of today's electricity generated from renewables (and only 11 percent from wind and solar),[26] and with a growing suite of best practices available to manage variability and siting, the United States has room to build out renewables aggressively over the coming decades.

QUESTION 6 | **What does our energy future look like?**

Three elements of the coming energy transition hold constant across the wide variety of scenarios for addressing climate change in the United States and globally. They are as follows:

(1) Generate electricity from zero-carbon sources: A clean energy future starts with zero-carbon electricity. This includes further accelerating the deployment of renewable energy technologies, extending the lifespan of existing nuclear plants that are deemed safe to operate, and phasing out fossil (coal and natural gas) generation unless equipped with carbon capture and storage.

(2) Electrify and decarbonize buildings, transportation, and industry: In a clean energy future, end-uses of energy are powered by zero-carbon electricity or other zero-carbon fuels. In practice, this means that a growing share of vehicles are electric; that new buildings are designed use electric appliances rather than natural gas, and that existing buildings are retrofit to do the same; and that industrial facilities adopt best-in-class energy management and zero-carbon technologies.

(3) Make buildings, transportation, and industry more efficient: Rapid electrification and decarbonization of the energy sector will be much more feasible if all end-use sectors make better, more efficient use of energy. Strengthening fuel economy standards, appliance standards, and building codes are key elements of the solution.

Question 1 provides further detail on what Congress can do to advance each of these three pillars.

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[22] Grace C. Wu, Margaret S. Torn, and James H. Williams, "Incorporating Land-Use Requirements and Environmental Constraints in Low-Carbon Electricity Planning for California," *Environmental Science & Technology* 49, no. 4 (February 17, 2015): 2013–21, https://doi.org/10.1021/es502979v.
[23] https://www.awea.org/resources/news/2016/wind-power-pays-$222-million-a-year-to-rural-lando
[24] https://www.pri.org/stories/2018-06-08/energy-and-food-together-under-solar-panels-crops-thrive
[25] https://www.nrel.gov/docs/fy19osti/73992.pdf
[26] https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

Achieving a clean energy future offers a wide range of benefits for Americans[27]:

- Lower energy bills via cleaner, cheaper electric heating and cooling and more efficient buildings and appliances
- Better air quality and improved health via clean power and electric vehicles
- More diverse local economies with job options and revenue sources in the clean energy economy
- Support for fossil fuel workers with opportunities to gain new skills and pursue employment in clean energy and landscape restoration

QUESTION 7 | **How can communities have a voice in what powers our world?**

Americans are as concerned as ever about climate change, and support for expanding renewable energy is nearly ubiquitous. Two out of three Americans are at least "somewhat worried" about climate change, and three in ten are "very worried" about it.[28] Most believe that the federal government is not doing enough,[29] and in fact, legislative staff consistently underestimate their constituencies' support for climate action.[30] When it comes to renewable energy, the numbers are even more striking – 92 percent and 85 percent of Americans support expanding solar power and wind power, respectively, and this includes strong majorities of both Republicans and Democrats.[31]

These figures help explain why communities are increasingly taking action on clean energy, as reflected in the more than 150 US cities that have already committed to 100 percent renewable energy.[32] To achieve these goals, cities are signing increasingly large power purchase agreements to source renewable electricity. In the eight states[33] that allow Community Choice Aggregation, a growing number of municipalities are procuring clean power for both municipal and community use.[34] In addition, communities are partnering with the private sector to reduce emissions, collaborating with one another to overcome hurdles such as state legislation, and engaging in regulatory proceedings to influence public utility commissions.[35]

Communities have also sought to exercise their voices via litigation and direct action. For example, at least eight cities and counties in California, along with New York City and municipalities in Colorado and Washington state, have filed public nuisance claims against fossil fuel companies,[36] and fossil fuel infrastructure projects including

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[27] https://www.bbhub.io/dotorg/sites/28/2019/12/Accelerating-Americas-Pledge.pdf
[28] https://climatecommunication.yale.edu/wp-content/uploads/2019/12/Climate_Change_American_Mind_November_2019b.pdf
[29] https://www.pewresearch.org/science/2019/11/25/u-s-public-views-on-climate-and-energy/
[30] Alexander Hertel-Fernandez, Matto Mildenberger, and Leah C. Stokes, "Legislative Staff and Representation in Congress," *American Political Science Review* 113, no. 1 (February 2019): 1–18, https://doi.org/10.1017/S0003055418000606.
[31] https://www.pewresearch.org/science/2019/11/25/u-s-public-views-on-climate-and-energy/
[32] https://www.sierraclub.org/ready-for-100/commitments
[33] California, Illinois, Massachusetts, New Jersey, New York, Ohio, Rhode Island and Virginia
[34] https://leanenergyus.org/cca-by-state/
[35] https://www.wri.org/blog/2020/01/watch-these-4-clean-energy-trends-us-cities-2020
[36] https://insideclimatenews.org/news/04042018/climate-change-fossil-fuel-company-lawsuits-timeline-exxon-children-california-cities-attorney-general

eight new oil terminals in the Pacific Northwest[37] and two gas pipelines in Appalachia have faced community opposition.[38]

While there is much that communities can do to advance clean energy in the United States, local action alone is insufficient to deliver on the energy transition that Americans agree needs to happen. Federal engagement as outlined under Questions 1-3 is needed to complement leadership by frontrunner communities.

QUESTION 8 | **Is there anything else that you would like to address that you did not get a chance to address during the hearing?**

The minority witness' testimony[39] contained several inaccuracies and mischaracterizations that are addressed below at the suggestion of Committee staff.

p. 4: *In 2017 a large team of scientists modeled 37 different regions across the U.S. and found that "humans may not only influence fire regimes but their presence can actually override, or swamp out, the effects of climate." Of the 10 variables that influence fire, they wrote, "none were as significant... as the anthropogenic variables," such as building homes near, and managing fires and wood fuel growth within forests.*

The study[40] does not refer to variables "that influence fire," but rather to variables that influence *the variance in the climate-fire relationship* across regions of the United States. That is, the authors are seeking to understand why climate is a stronger influence on fire in some regions than in others, and they find that human-related factors have an important role in explaining these regional differences. The study also finds that on average, across 37 regions of the United States, climate-related variables explain 29 percent of the variance in fire activity on federal lands over the past 40 years. Evaluating a separate data set spanning greater land cover over the past 20 years, the study finds that climate explains 42 percent of average fire activity variance. Key factors include high summer and spring temperatures and prior-year precipitation.

p. 5: *Humans today produce enough food for 10 billion people, a 25 percent surplus. ... FAO projects farmers in sub-Saharan Africa could see crop yields increase 80 to 90 percent.*

The world currently produces enough *crops* to feed 10 billion people, under certain conditions that are not currently met. More than 25 percent of current crop production goes to animal feed, another six to biofuels and other uses, around a third is lost or wasted, and the remainder is highly unequal in distribution. As a result, more than 800 million people today are chronically hungry.[41]

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[37] https://wecprotects.org/program/stop-coal-and-oil-export/
[38] https://www.cbc.ca/news/business/america-pipelines-protest-1.4806452
[39] Page numbers in this section refer to the document available at the following link, accessed February 18, 2020: https://science.house.gov/imo/media/doc/Shellenberger%20Testimony.pdf
[40] Alexandra D. Syphard et al., "Human Presence Diminishes the Importance of Climate in Driving Fire Activity across the United States," *Proceedings of the National Academy of Sciences* 114, no. 52 (December 26, 2017): 13750–55, https://doi.org/10.1073/pnas.1713885114.
[41] For a detailed discussion, see p. 16, Tim Searchinger et al., "Creating a Sustainable Food Future: A Menu of Solutions to Feed Nearly 10 Billion People by 2050," World Resources Report (World Resources Institute, July 2019), https://wrr-food.wri.org/sites/default/files/2019-07/WRR_Food_Full_Report_0.pdf.

With regard to sub-Saharan Africa, the FAO projects yield increases ranging from 0 to 17 percent in 2030 and 6 to 32 percent by 2050 relative to 2012.[42] To put this in context, the region's population is expected to grow by 60 percent by 2030 and 140 percent by 2050 relative to 2012.[43]

p. 5: *Humans are not on the precipice of a tipping point with regards to the melting of tundra in ways that would result in the rapid release of methane gas, concludes IPCC.*

What the IPCC says is that *at 2°C of warming*, the carbon released from thawing permafrost would be restricted to 0.09-0.19 GtC per year, which would not constitute a tipping point. The report goes on to say that "at higher degrees of global warming, in the order of 3°C, a different type of tipping point in permafrost may be reached." Of course, under current policies and pledges, we are on track for 3 to 3.5°C of warming, putting us in the potential tipping point zone.[44]

p. 5: *...the IPCC says, "There is only limited evidence linking the current anomalously weak state of AMOC to anthropogenic [human-caused] warming," and that it has high confidence that is "very unlikely it will shut down before 2100."*

In the same paragraph, the IPCC says: "It is very likely that the AMOC will weaken over the 21st century" and later mentions that the weakening is very likely to be substantial under >2°C of warming.[45] Why is this important? "Weakening of the AMOC...is projected to be highly disruptive to natural and human systems as the delivery of heat to higher latitudes via this current system is reduced."[40, 46]

p. 6: *If the Greenland ice sheet were to completely disintegrate, sea levels would rise by seven meters, but over a 1,000-year period. And for that to happen, temperatures would have to rise far more than anyone imagines.*

Regarding the Greenland ice sheet, the IPCC says the following: "Various feedbacks between the Greenland ice sheet and the wider climate system, most notably those related to the dependence of ice melt on albedo and surface elevation, make irreversible loss of the ice sheet a possibility. Church et al. (2013) assessed this threshold to be at 2°C of warming or higher levels relative to pre-industrial temperature. Robinson et al. (2012) found a range for this threshold of 0.8°C–3.2°C (95% confidence)."[40, 47]

p. 6: *The good news is that the world appears to be headed to temperatures closer to two degrees than four....*

This is not correct. The latest estimate comes from the 2019 *UNEP Emissions Gap Report*, which is based on a comprehensive review of the greenhouse gas scenarios literature and gives a median estimate of 3.5°C under

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[42] Food & Agriculture Organization, *Future of Food and Agriculture 2018: Alternative Pathways to 2050.* (Rome: FAO, 2018).
[43] https://blogs.worldbank.org/opendata/worlds-population-will-continue-grow-and-will-reach-nearly-10-billion-2050
[44] For further information, *Carbon Brief* has a very useful explainer of permafrost, AMOC, Greenland ice sheet disintegration and other potential tipping points, available at https://www.carbonbrief.org/explainer-nine-tipping-points-that-could-be-triggered-by-climate-change
[45] IPCC, "Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (Eds.)]." Chapter 3, p. 212.
[46] Ibid. Chapter 3, p. 223.
[47] Ibid. Chapter 3, p. 257.

current policies, 3.2°C if countries achieve their unconditional nationally determined contributions under the Paris Agreement, and 3.0°C if countries achieve their more ambitious conditional nationally determined contributions. (Countries collectively are not currently on track to achieve either the unconditional nor the conditional nationally determined contributions.) The literature review conducted as input to the *Gap Report* did not unveil any analysis indicating that the world is currently on track for warming in the range of 2°C.

p. 7: *A new report by the International Energy Agency (IEA) forecasts carbon emissions in 2040 to be lower than in almost all of the IPCC scenarios.*

This is not correct. As outlined under Question 4 and as illustrated in Figure 1, the WEO scenarios associated with current and stated policies show 2040 emissions well above IPCC scenarios consistent with limiting warming to 1.5 and 2°C. Only the WEO Sustainable Development Scenario – which is not a forecast but rather a hypothetical illustration of how the world might "take effective action to combat climate change" – falls within the range of IPCC scenarios consistent with limiting warming to 1.5 and 2°C.

Appendix: Priority Areas for Clean Energy Innovation RD&D

Topics are listed in priority order.

Power

1. **Advanced power cycles**. Much of today's power generation relies on Rankine-cycle steam turbines, which have limited efficiencies. New power cycles, particularly supercritical CO2 Brayton cycle turbines and Allam-cycle turbines, could offer significantly higher efficiencies and lower emissions. These turbines are applicable to solar thermal, nuclear, geothermal, coal and gas fired power generation.

2. **Stationary energy storage**. Integrating variable renewables into the electric grid will require advances in bulk energy storage, including advanced battery systems, expanded use of pumped hydro, compressed-air energy storage (CAES), flywheels, and improved data and algorithms for storage dispatch and control.

3. **Long-distance power transmission**. Reducing costs of HVDC technology and developing alternative siting strategies (such as underground and along rail corridors) will enable greater use of renewable energy in locations far from population centers.

4. **Offshore and high-altitude wind**. Steadier, stronger winds offshore and at high altitudes can provide enormous increases in renewable energy generation, but new technologies are needed to access them. Offshore wind platform construction and maintenance, and high-altitude wind generation such as kite wind are needed.

5. **Ultra-low-cost PV**. While silicon-based solar PV is getting cheaper, it is approaching cost-reduction limits. New materials and technologies are emerging (including perovskites and CPV) that may drive costs to as low as 10-20 cents/W, up to 80% cheaper than current technologies.

6. **Small modular reactors**. Zero-carbon nuclear power can contribute to meeting emissions-reduction targets in the power sector. Small modular reactors can deploy more quickly and take better advantage of standardization and factory-based assembly. SMRs can also provide low-carbon industrial process heat when suitably designed.

7. **Advanced geothermal**. Geothermal power plays a vital role as a fully dispatchable renewable generation source. The US has large subsurface geothermal resources that it has not yet exploited. Improved methods for characterizing these resources, stimulating them for better production, and reducing the costs of drilling are needed.

Transportation

1. **Advanced vehicle batteries and charging**. Electric vehicles offer low-carbon transportation, particularly when charged from a low-carbon grid. Improved lightweight battery chemistries are needed to further reduce EV costs. Better technologies for battery recycling and transfer to stationary storage are also needed. Low-cost and alternative fast-charging systems are also needed.

2. **Vehicle lightweighting**. Low-cost, non-fossil-derived carbon fiber for vehicles and aerospace and advanced aluminum and magnesium alloys can reduce fuel consumption and emissions by reducing vehicle weight.

3. **Autonomous efficiency**. New strategies for vehicle platooning, optimal routing, and efficient drive cycles are all possible with increasing vehicle automation and can reduce fuel consumption as well as reduce congestion and idling emissions.

4. **Advanced biofuels and bioproducts.** Producing drop-in biofuels and bioproducts from algal and lignocellulosic biomass can reduce pressure on land for food production and displace carbon-intense materials in the broader economy.

Buildings and industrial processes

1. **Low-carbon industrial process heat**. Providing alternative, low-carbon sources of medium- to high-temperature heat for industrial process is necessary for reducing emissions in a variety of manufacturing sectors. This may include solid oxide fuel cells, particularly in CHP configurations.

2. **High-efficiency electric heating**. Ultra-high-efficiency heat pumps and non-vapor-compression heating/cooling systems are needed to provide low-emissions space conditioning.

3. **Carbon fiber construction and retrofitting**. Architectural innovation to use carbon fiber replacements for steel and in retrofitting applications could improve overall building/construction life-cycle efficiencies.

Enabling technologies

1. **Low-carbon hydrogen**. Hydrogen produced using low-cost renewable energy, renewable biomass, or fossil fuel with carbon capture and storage can become a central part of a low-carbon economy, including transportation, industrial process heat, and power generation. Improved hydrogen generation, storage, and transport/pipeline technologies are needed for this.

2. **Carbon fiber production and recycling**. Non-fossil-derived low-cost carbon fiber could enable vehicle lightweighting, architectural applications, aerospace and marine applications, and infrastructure construction and repair.

3. **Thermal storage**. Low-cost methods for bulk storage of thermal energy would allow better use of waste heat, more efficient heating/cooling cycles, improved building efficiency, and overall performance improvements across many technologies.

4. **High-efficiency cooling.** Advanced materials and technologies for fast, low-energy/passive cooling would improve efficiencies for power generation, building operation, industrial processes, vehicles, and other systems.

5. **Wide-bandgap semiconductors**. Improved WBG materials can enable a wide range of power-conversion applications in stationary and transport contexts.

Other

1. **CO_2 conversion and utilization**. Captured CO_2 can be utilized for economically valuable purposes, including polymers and chemicals, building materials, animal feed, and carbon fiber. Improved technologies for chemical and biological conversion of CO_2 to useful forms are needed.

Increased focus areas	WRI recommendation ($ millions)	FY19 enacted ($ millions)	Department of Energy: Congressional control account
Advanced energy technologies; funds 10 new $30 million/3 year programs	665	365	ARPA-E
Advanced energy storage; vehicle lightweighting; wide-bandgap semiconductors; carbon fiber production and recycling; high-efficiency cooling;	490	320	EERE/Advanced Manufacturing
Algal and lignocellulosic drop-in biofuels and bioproducts; biomass to carbon fiber; biomass hydrogen production	296	226	EERE/Bioenergy Technologies
High-efficiency heating; Carbon fiber construction and retrofitting	276	226	EERE/Building Technologies
Advanced geothermal; advanced power cycles	144	84	EERE/Geothermal Technologies
Low-carbon hydrogen production, storage and transportation	170	120	EERE/Hydrogen and Fuel Cell Technologies
Ultra-low-cost PV; advanced power cycles	317	247	EERE/Solar Energy Technologies
Advanced transportation batteries and fast charging; vehicle light-weighting; autonomous efficiency	459	344	EERE/Vehicle Technologies
Pumped hydro storage	115	105	EERE/Water Power Technologies
Offshore and high-altitude wind	142	92	EERE/Wind Energy Technologies
Advanced power cycles; stationary fuel cells	205	130	FE/Advanced Energy Systems [1]
CO2 conversion and utilization; low-carbon fossil hydrogen production	264	199	FE/Carbon Capture, Utilization and Storage
Small modular reactors; sCO2 Brayton cycle turbines	419	324	NE/Reactor Concepts RD&D
Stationary energy storage	71	46	OE/Energy Storage
HVDC; alternative transmission siting	79	39	OE/Transmission Reliability and
	4,112	**2,867**	**TOTALS**

Appendix II

Additional Material for the Record

LETTER SUBMITTED BY REPRESENTATIVE EDDIE BERNICE JOHNSON

NATIONAL PARKS CONSERVATION ASSOCIATION
EST 1919

NPCA Position for House Committee on Science, Space, and Technology Hearing:
An Update on the Climate Crisis: From Science to Solutions

January 14th, 2020

Dear Representative,

Since 1919, National Parks Conservation Association (NPCA) has been the leading voice of the American people in protecting and enhancing our National Park System. On behalf of our nearly 1.4 million members and supporters nationwide, I write to share our thoughts for the House Committee on Science Space and Technology Hearing *An Update on the Climate Crisis: From Science to Solutions* scheduled for January 15th.

The spectacular sites throughout our National Park System are not just ideal places to enjoy the wonders of nature and learn from pivotal events in America's history. They are also critical hotspots for the scientific research needed to combat the growing threat of climate change. Our national parks continue to serve as living laboratories for scientists and resource managers, as well as places to teach the next generation of conservation leaders. The resources, accessibility, unspoiled nature and remarkable geographic distribution of our national parks make them the greatest collection of study sites a scientist could ask for, especially at a time of environmental upheaval. Additionally, these beloved places capture the imagination and inspire a strong, national conservation ethic.

Yet an appreciation for hard-earned science has dropped sharply in our current political climate, in ways that could profoundly harm the parks and cause damage to the integrity of science. The Trump administration has proposed devastating cuts to science-based agencies, most recently, for example, a 12 percent cut to the National Science Foundation and a 12 percent cut to the Institutes of Health. Science has no political agenda; it is a process that explores how to best answer questions through a carefully structured approach, has an extremely rigorous set of filters, relies on carefully collected data and repeatable testing, and is subject to a grueling system of review. The polarized perception of science we are seeing today is inconsistent with the history of the National Park Service — and for that matter, the history of the United States.

When science is undermined, suppressed or misrepresented for political purposes, we all suffer the consequences. There are numerous examples of this; agency staff denied opportunities to share their research publicly, whole portions of reports removed before publication, agency staff told to remove mention of humans' role in causing climate change.

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This is coming at a time when there is no bigger threat to the future of our nation than climate change. It is already destroying what these treasured places were created to preserve – our wilderness, history and culture. Temperatures in national parks are warming twice as fast as the rest of the country, threatening the very existence of namesake features at Glacier, Joshua Tree and Saguaro National Parks. Cape Hatteras National Seashore is eroding into the sea from rising tides, and Rocky Mountain National Park is experiencing record wildfires, scaring the landscape and devastating nearby communities and local economies. These places offer a view of climate change's devastating impact on our land as 80 percent of our more than 400 national parks are currently experiencing changes in climate through extreme trends in temperature, precipitation or early onset of the spring season.

Just as national parks cannot survive in isolation and depend heavily on the matrix of habitat and ecosystems that surround them, parks also cannot survive without informed decision-making based on science. The way in which federal lands are managed comes from collaborative, joint and communal scientific resources that serve all bureaus of the Department of the Interior. As an example, protecting critically endangered species requires high quality data generated from the U.S. Fish & Wildlife Service to inform management strategies and recovery plans within the National Park Service. Air quality data from the Environmental Protection Agency is crucial to helping national parks determine whether visitors will encounter haze and other safety concerns. The U.S. Geological Survey's monitoring of wind, tide and currents contributes to the management of the 88 coastal national park sites that need to plan for recreation, infrastructure and the protection of resources from extreme weather events.

Science and scientific discovery have a surprisingly strong legacy in our parks. In fact, entire disciplines in science recognized around the world came from discoveries in our national parks. The theory of ecological niche, ecological succession, Carbon-14 isotopic research and the world's longest running predator-prey study can be traced back to national park sites. Today, researchers are working actively in most park units, spanning all fields of science including light pollution, social sciences (visitor behavior), hydrology, fire ecology, climate change, and mammal and bird migration. And for over a century, the National Park Service has seamlessly collected scientific data that provides invaluable baseline information on the natural world shared with all other federal agencies. Scientists can better understand air quality in the Great Smoky Mountains, for example, because park staff have been analyzing the air at the park for decades, providing a rich understanding of how the environment is changing.

The integrity of science has never been more important to our National Park System than it is right now. Our public lands are the canary in the coal mine of climate change. How our parks can adapt to threats like climate change, wildfires, flooding or species loss relies heavily on whether the Park

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NATIONAL PARKS CONSERVATION ASSOCIATION
EST 1919

Service continues to have access to the best available science and information to make sound and informed decisions – so we may enjoy these places for generations to come.

Thank you for your consideration of our views. Please contact Tucker Johnson at tjohnson@npca.org if you have any questions or concerns.

Sincerely,

Ani Kame'enui
Deputy Vice President, Government Affairs

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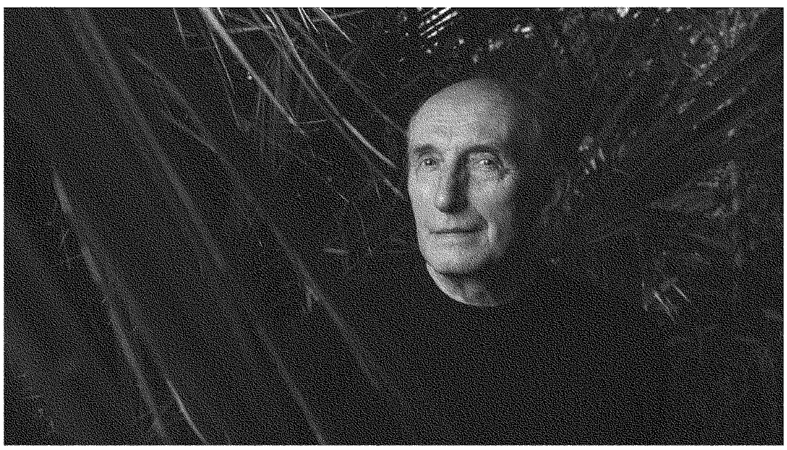
ARTICLE SUBMITTED BY REPRESENTATIVE ANTHONY GONZALEZ



Through dozens of books, Vaclav Smil has helped shape how people think about the past and future of energy.
DAVID LIPNOWSKI

Meet Vaclav Smil, the man who has quietly shaped how the world thinks about energy

By **Paul Voosen** | Mar. 21, 2018 , 9:00 AM

As a teenager in the 1950s, Vaclav Smil spent a lot of time chopping wood. He lived with his family in a remote town in what was then Czechoslovakia, nestled in the mountainous Bohemian Forest. On walks he could see the Hohenbogen, a high ridge in neighboring West Germany; less visible was

Throughout his career, Smil, perhaps the world's foremost thinker on energy of all kinds, has sought clarity. From his home office near the University of Manitoba (UM) in Winnipeg, Canada, the 74-year-old academic has churned out dozens of books over the past 4 decades. They work through a host of topics, including China's environmental problems and Japan's dietary transition from plants to meat. The prose is dry, and they rarely sell more than a few thousand copies. But that has not prevented some of the books—particularly those exploring how societies have transitioned from relying on one source of energy, such as wood, to another, such as coal—from profoundly influencing generations of scientists, policymakers, executives, and philanthropists. One ardent fan, Microsoft co-founder Bill Gates in Redmond, Washington, claims to have read nearly all of Smil's work. "I wait for new Smil books," Gates wrote last December, "the way some people wait for the next *Star Wars* movie."

Now, as the world faces the daunting challenge of trying to curb climate change by weaning itself from fossil fuels, Smil's work on energy transitions is getting more attention than ever. But his message is not necessarily one of hope. Smil has forced climate advocates to reckon with the vast inertia sustaining the modern world's dependence on fossil fuels, and to question many of the rosy assumptions underlying scenarios for a rapid shift to alternatives. "He's a slayer of bullshit," says David Keith, an energy and climate scientist at Harvard University.

Give Smil 5 minutes and he'll pick apart one cherished scenario after another. Germany's solar revolution as an example for the world to follow? An extraordinarily inefficient approach, given how little sunlight the country receives, that hasn't reduced that nation's reliance on fossil fuels. Electric semitrailers? Good for little more than hauling the weight of their own batteries. Wind turbines as the embodiment of a low-carbon future? Heavy equipment powered by oil had to dig their foundations, Smil notes, and kilns fired with natural gas baked the concrete. And their steel towers, gleaming in the sun? Forged with coal.

"There's a lot of hopey-feely going on in the energy policy community," says David Victor, an expert on international climate policy at the University of California, San Diego. And Smil "revels in the capability to show those falsehoods."

But Smil is not simply a naysayer. He accepts the sobering reality of climate change—though he is dubious of much climate modeling—and believes we need to reduce our reliance on fossil fuels. He

Despite Smil's reach—some of the world's most powerful banks and bureaucrats routinely ask for his advice—he has remained intensely private. Other experts tap dance for attention and pursue TED talks. But Smil is a throwback, largely letting his books speak for themselves. He loathes speaking to the press (and opened up to *Science* only out of a sense of duty to The MIT Press, his longtime publisher). "I really don't think I have anything special to say," he says. "It's out there if you want to know it."

An Iron Curtain childhood

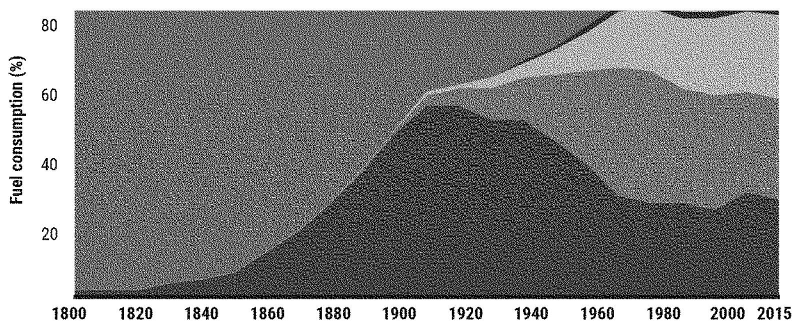
This past December, Smil stepped out of a hotel in Washington, D.C., and pulled on a knit cap—he'd allow no wasted heat, especially given a persistent head cold. He had given a lecture the previous day and now was making a beeline for a favorite spot: the National Gallery of Art. He was a regular in the nation's capital during the 1980s and '90s, consulting with the World Bank, the Central Intelligence Agency, and other government agencies. But the United States's security clampdown after 9/11—its the increasing political dysfunction—soured him on the country's leaders. "This government is so inept," he said. "It cannot even run itself in the most basic way."

Still, Smil can't shake his affection for the United States. It goes back to his childhood: During World War II, U.S. soldiers—not Soviet troops—liberated his region from the Nazis. And it was to the United States that Smil and his wife, Eva, fled in 1969, after the Soviets invaded Czechoslovakia to stymie a political uprising.

Nothing was exceptional about his childhood, Smil says. His father was a police officer and then worked in manufacturing; his mother kept the books for a psychiatric hospital's kitchen. But even as a boy, he was aware of the miasma of falsehood that surrounded him in Cold War Czechoslovakia, and it spurred his respect for facts. "I'm the creation of the communist state," he says, recalling how, as a child, he heard that the Soviet Union had increased production of passenger cars by 1000% in a single year. "I looked at it and said, 'Yeah, but you started from nothing.'" Officials would claim they had exceeded their food plan, yet oranges were never available. "It was so unreal and fake," Smil says. "They taught me to respect reality. I just don't stand for any nonsense."

Energy inertia

The transition from wood ("traditional biofuels") to fossil fuels—first coal, then oil and natural gas—took more than a century. Today, fossil energy is dominant, with wind and solar making up a mere sliver of the mix. The pace of past energy transitions suggests that a full-scale shift to renewables will be slow.



(GRAPHIC) J. YOU/*SCIENCE*; (DATA) V. SMIL, ENERGY TRANSITIONS, PRAEGER, 2017; V. SMIL, POWER DENSITY, MIT PRESS, 2015

As an undergraduate, Smil studied the natural sciences at Charles University in Prague. He lived in an old converted cloister. Its thick stone walls kept it chilly, summer and winter. And in the first of Smil's personal energy transitions, heat came not from wood, but from coal—hard black anthracite from Kladno or dirty brown lignite from North Bohemia.

He got to indulge his curiosity, taking 35 classes a week, 10 months a year, for 5 years. "They taught me nature, from geology to clouds," he says. But Smil decided that a traditional scientific career was not for him. No lab bench called: He was after the big picture.

After graduation, he also realized that his future would not be in his homeland: He refused to join the Communist Party, undermining his job prospects. He worked in a regional planning office while Eva pursued her medical degree. After Soviet troops invaded, many friends and neighbors panicked and left. But the couple waited for Eva's graduation, dreading a travel ban. They finally departed in 1969, just months before the government imposed a travel blockade that would last for decades. "That was not a minor sacrifice, you know?" Smil says. "After doing that, I'm not going to sell myself for photovoltaics or fusion or whatever and start waving banners. Your past always leads to who you are."

The Smils ended up at Pennsylvania State University in State College, where Vaclav completed a doctorate in geography in 2 years. With little money, they rented rooms from a professor's widow, of every answer was correct, and every combination in between," says Rick Baydack, chair of the environmental science department at UM, who was once Smil's student.

Otherwise, Smil was a ghost in his department, taking on only a few graduate students. Since the 1980s, he has shown up at just one faculty meeting. But as long as he kept teaching and turning out highly rated books, that was fine for the school. "He's a bit of a recluse and likes to work on his own," Baydack says. "He's continued down a path he set for himself. What's happening around him doesn't really matter."

Rootless bohemian cosmopolitan

Today, Smil straddles the line between scientist and intellectual, flashing the tastes of a "rootless bohemian cosmopolitan," as his old communist masters used to call him. He's fluent in a flurry of languages. He's a tea snob and foodie who is reluctant to eat out because so much restaurant food is now premade. Stand in a garden and he can tell you the Latin names of many of the plants. He's an art lover: Mention the Prado Museum in Madrid and he might tell you the secret of finding 5 minutes without crowds to appreciate Diego Velázquez's *Las Meninas*, his favorite painting, which depicts a Spanish princess encircled by her retinue. And then he'll say, "I appreciate and love blue-green algae," which helped kick off Earth's oxygen age. "They are the foundation."

Smil's breadth feels anachronistic. In modern academic science, all the incentives push to narrow specialization, and Smil believes his eclectic interests have complicated his career. But his ability to synthe-size across disparate fields also has proved a strength, enabling him to trace how energy courses through every capillary of the world's economy.

Smil's writing career kicked off in the mid-1970s, just as an embargo on oil sales by Middle Eastern nations woke up developed nations to just how hooked they were on petroleum, for transportation, heating, farming, chemicals, even electricity. The jolt came just after the publication of *The Limits to Growth*, an influential study that, using a simple computer model, warned of a pending depletion of the planet's resources.

> **You could take a paragraph from one of his books and make a whole career out of it. [He] does a really good job of being nuanced.**
>
> *Elizabeth Wilson, Dartmouth College*

clouds. Ever since, he's held models of all kinds in contempt. "I have too much respect for reality," he says.

Instead, he scoured the scientific literature and obscure government documents for data, seeking the big picture of how humanity generates and deploys energy. What ultimately emerged in several blandly titled books—including *General Energetics: Energy in the Biosphere and Civilization* (1991), *Energy in World History* (1994), and *Energy Transitions: History, Requirements, Prospects* (2010)—is an epic tale of innovation and transformation, worked through one calculation at a time.

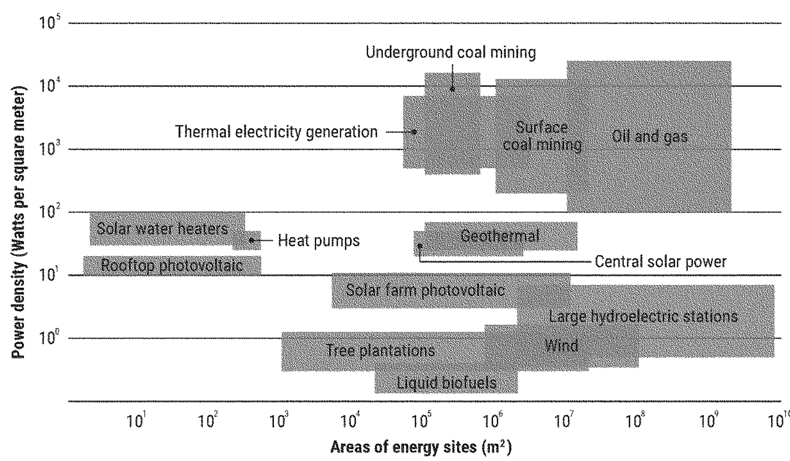
That work has guided a generation to think about energy in the broadest sense, from antiquity to today, says Elizabeth Wilson, director of the Institute for Energy and Society at Dartmouth College. "You could take a paragraph from one of his books and make a whole career out of it," she says. And yet Smil has avoided mental traps that could come with his energy-oriented view, she adds. "[He] does a really good job of being nuanced."

In essence, Smil says, humanity has experienced three major energy transitions and is now struggling to kick off a fourth. First was the mastery of fire, which allowed us to liberate energy from the sun by burning plants. Second came farming, which converted and concentrated solar energy into food, freeing people for pursuits other than sustenance. During that second era, which ended just a few centuries ago, farm animals and larger human populations also supplied energy, in the form of muscle power. Third came industrialization and, with it, the rise of fossil fuels. Coal, oil, and natural gas each, in turn, rose to prominence, and energy production became the domain of machines, as such coal-fired power plants.

Now, Smil says, the world faces its fourth energy transition: a move to energy sources that do not emit carbon dioxide, and a return to relying on the sun's current energy flows, instead of those trapped millions of years ago in deposits of coal, oil, and natural gas.

The fourth transition is unlike the first three, however. Historically, Smil notes, humans have typically traded relatively weak, unwieldy energy sources for those that pack a more concentrated punch. The wood he cut to heat his boyhood home, for example, took a lot of land area to grow, and a single log produced relatively little energy when burned. Wood and other biomass fuels have relatively low "power density," Smil says. In contrast, the coal and oil that heated his later dwellings have higher power densities, because they produce more energy per gram and are extracted from relatively compact deposits. But now, the world is seeking to climb back down the power density ladder, from highly concentrated fossil fuels to more dispersed renewable sources, such as biofuel crops, solar parks, and wind farms. (Smil notes that nuclear power, which he deems a "successful failure" after

In the past, humanity has typically adopted energy sources that have greater "power density," packing more punch per gram and requiring less land to produce. Renewables (green), however, are lower in density than fossil fuels (brown). That means a move to renewables could vastly increase the world's energy production footprint, barring a vast expansion of nuclear power.



(GRAPHIC) J. YOU/*SCIENCE*; (DATA) V. SMIL, ENERGY TRANSITIONS, PRAEGER, 2017; V. SMIL, POWER DENSITY, MIT PRESS, 2015

One troubling implication of that density reversal, Smil notes, is that in a future powered by renewable energy, society might have to devote 100 or even 1000 times more land area to energy production than today. That shift, he says, could have enormous negative impacts on agriculture, biodiversity, and environmental quality.

To see other difficulties associated with that transition, Smil says, look no further than Germany. In 2000, fossil fuels provided 84% of Germany's energy. Then the country embarked on a historic campaign, building 90 gigawatts of renewable power capacity, enough to match its existing electricity generation. But because Germany sees the sun only 10% of the time, the country is as hooked as ever on fossil fuels: In 2017, they still supplied 80% of its energy. "True German engineering," Smil says dryly. The nation doubled its hypothetical capacity to create electricity but slow, painstaking, and hard to predict. And existing technologies have a lot of inertia. The first tractor appeared in the late 1800s, he might say, but the use of horses in U.S. farming didn't peak until 1915—and continued into the 1960s.

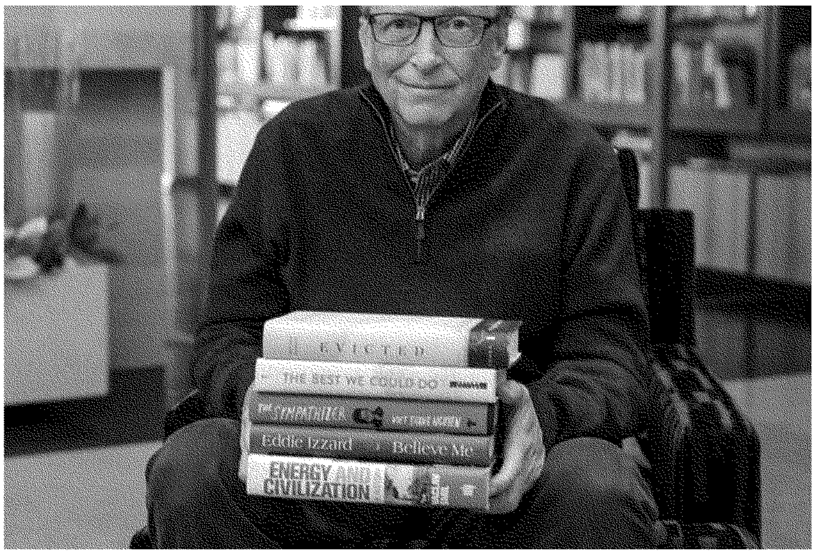
Fossil fuels have similar inertia, he argues. Today, coal, oil, and natural gas still supply 90% of the world's primary energy (a measure that includes electricity and other types of energy used in industry, transportation, farming, and much else). Smil notes that the share was actually lower in 2000, when hydropower and nuclear energy made up more of the mix. Since then, "we have been increasing our global dependence on fossil fuels. Not decreasing," he says.

A key factor has been the economic boom in China, a nation Smil has studied since the 1970s, and its burgeoning appetite for coal. Smil was among the first Western academics invited to study the Chinese energy system. He sounded early warnings about the nation's cooked farm statistics and perilous environmental state. Now, Smil is disheartened by China's consumer culture: Instead of aiming to live more modestly, he says the Chinese are "trying to out-America America."

Meanwhile, despite years of promotion and hope, wind and solar account for just about 1% of the world's primary energy mix. In part, he notes, that's because some of the key technologies needed to deploy renewable energy on a massive scale—such as higher-capacity batteries and more efficient solar cells—have seen only slow improvements. The bottom line, he says, is that the world could take many decades to wean itself from fossil fuels.

An odd couple

Smil sees few options for hastening the transition. And that is where he and some of his biggest fans—including Gates—diverge. Smil's realism appeals to Gates, who first mentioned Smil on his blog in 2010. Like many tech tycoons, Gates had made failed investments over the previous decade in biofuels, a technology Smil has scorned because it is so land-hungry. Over the next year, Gates, who declined to be interviewed for this story, publicly detailed his conversion to Smilism. It was not an easy one: After reading his first Smil book, Gates "felt a little beat up. ... Am I ever going to be able to understand all of this?" But he ultimately concluded that "I learn more by reading Vaclav Smil than just about anyone else." That enthusiasm has written Smil's epitaph: "I'll forever be Bill Gates's scientist," Smil says.



Microsoft co-founder Bill Gates is an avid reader of Vaclav Smil's books, including *Energy and Civilization*, at the bottom of this stack. "I learn more by reading [him] than just about anyone else," Gates has written. THE GATES NOTES, LLC

The two have met just a few times, but they email regularly. And Gates has opened doors for Smil: Swiss banks weren't calling for his advice before. But they keep the relationship pure. "I would never ask him for any favor—never ever," Smil says. "As simple as that."

But when it comes to the future of energy, they make an odd couple. In 2016, Gates helped start Breakthrough Energy Ventures, a billion-dollar fund to speed clean energy innovations from the lab to market. "I am more optimistic than [Smil] is about the prospects of speeding up the process when it comes to clean energy," Gates has written. Smil puts it another way: "He's a techno-optimist, I'm a European pessimist."

Smil says that pessimism is rooted in his understanding of history. But even some of his fans say he puts too much stock in the lessons of the past. "Sometimes I've heard him speak too confidently" don't worry at all. With my wind and photovoltaics I can take care of everything.' But we are nowhere close to it," he says.

A personal take on solutions

When not on the road, Smil lives a quiet life in Winnipeg. He cultivates hot peppers, tomatoes, and basil in containers. (Deer would eat a traditional garden.) He cooks meals in Indian or Chinese styles, eating meat maybe once a week. He drives a Honda Civic, "the most reliable, most efficient, most miraculously designed car." He built his current home in 1989, a modest house of about 200 square meters. He used thicker-than-standard studs and joists, so he could stuff 50% more insulation into the walls, and all of the windows are triplepaned. There's a 97% efficient natural gas furnace. "My house," he says, is "a very efficient machine for living."

Despite those choices—and all that can be learned from his work—Smil is not comfortable offering solutions. Any he suggests typically come down to encouraging individual action, not sweeping government policies or investment strategies. If we all cut consumption, lived more efficiently, and ate less meat, he suggested at one recent lecture, the biosphere would do fine. Fewer livestock, for instance, might mean farmers would stop overfertilizing soybeans to feed to animals. Less fertilizer, in turn, would drastically cut emissions of nitrous oxide, a powerful greenhouse gas, from the soil. "Less pork and less beef, right? That's it," Smil says. "Nobody is really talking about it."

Such statements can make Smil sound as though he were an author of *The Limits to Growth*—not a critic. And the reality is that "there are many Vaclavs," says Ted Nordhaus, an environmentalist and executive director of The Breakthrough Institute, an environmental think tank in Oakland, California. There is the hard-edged skeptic, and then "there are times where Vaclav will be an old-fashioned conservationist. We could all be perfectly happy living at the level of consumption and income as Frenchmen in 1959."

Smil doesn't apologize for his contradictions. And for all his insistence on documenting reality, he accepts that many concepts cannot be defined. What does a healthy society look like, and how do you measure it? He abhors gross domestic product, the traditional measure used by economists, because even horrendous events—natural disasters and shootings, for example—can prompt spending that makes it grow. But the alternatives don't look great, either. Happiness indexes? Some of "the happiest nations on the planet are Colombia and the Philippines," Smil says. "What does that tell you?"

Lately, he's been thinking about growth, the obsession of modern, fossil-fueled economies and the antithesis of Smil's lifestyle of efficient, modest living. How do children grow? Energy systems?

how fast China would grow. And he is not about to say that a collapse is inevitable now—not even with humanity on a problematic course and unlikely to change direction soon. "You ask me, 'When will the collapse come?'" Smil says. "Constantly we are collapsing. Constantly we are fixing."

Posted in: **Engineering**, **People & Events**, **Scientific Community**, **Technology**

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Paul Voosen

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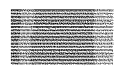

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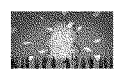

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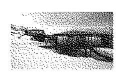

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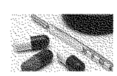

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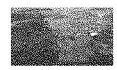

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REPORT SUBMITTED BY REPRESENTATIVE DON BEYER

NOAA reports near-record warm year for the globe

NOAA, NASA scientists confirm Earth's long-term warming trend continues

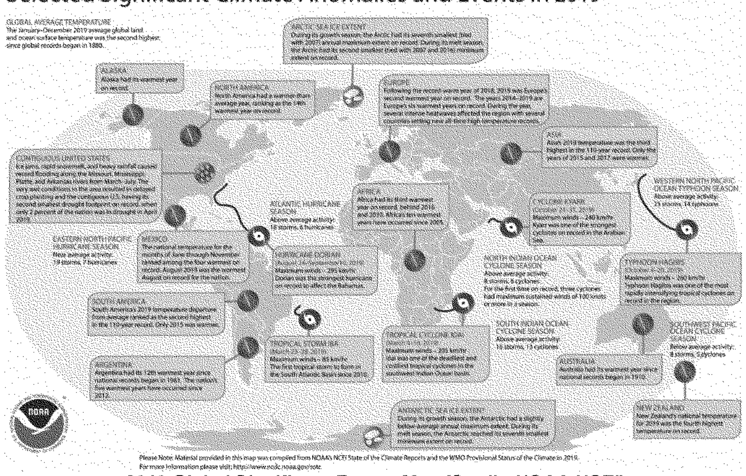
January 15, 2020

The globally averaged temperature departure from average over land and ocean surfaces for 2019 was the second highest since record keeping began in 1880, according to NOAA scientists. December's combined global land and ocean surface temperature departure from average for 2019 was also second highest in the 140-year record.

This summary from NOAA National Centers for Environmental Information is part of the suite of climate services NOAA provides to government, business, academia and the public to support informed decision-making.

In a separate analysis of global temperature data, released today, WMO, NASA and Copernicus scientists determined 2019 to also be the second warmest year on record. Analyses from the United Kingdom Met Office ranked 2019 among the top three warmest years on record.

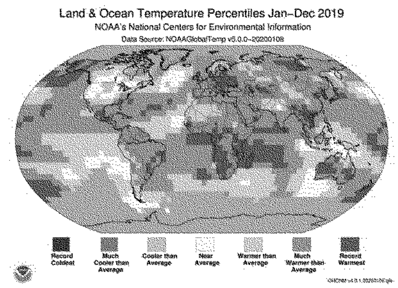
Selected Significant Climate Anomalies and Events in 2019



2019 Global Significant Events Map (Credit: NOAA NCEI)

2019 Global Climate Highlights

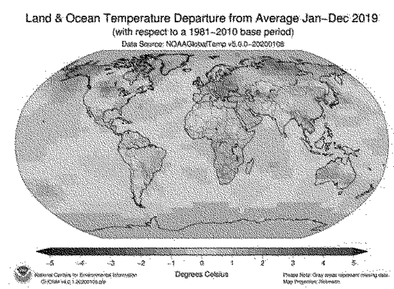
- <u>Global land and ocean surface temperature</u>: For 2019, the average temperature across global land and ocean surfaces was 1.71°F (0.95°C) above the 20th century average. This was the second highest among all years in the 1880-2019 record and just 0.07°F (0.04°C) less than the record value set in 2016.



2019 Global Average Temperature Percentiles Map (Credit: NOAA NCEI)

  - 2019 marks the 43rd consecutive year (since 1977) with global land and ocean temperatures, at least nominally, above the 20th century average.
  - The five warmest years have occurred since 2015; nine of the 10 warmest years have occurred since 2005. The year 1998 is the only 20th century year among the 10 warmest years on record.
  - The annual global land and ocean temperature has increased at an average rate of +0.13°F (+0.07°C) per decade since 1880; however, since 1981 the average rate of increase is more than twice that rate (+0.32°F / +0.18°C).
  - For the 21-year span that is considered a reasonable surrogate for pre-industrial conditions (1880-1900), the 2019 global land and ocean temperature was 2.07°F (1.15°C) above the average.

- <u>Global land surface temperature</u>: The globally averaged land surface temperature for 2019 was 2.56°F (1.42°C) above the 20th century average. This value tied with 2015 as the second highest among all years in the 140-year record, behind 2016.



2019 Global Temperature Departure from Average Map (Credit: NOAA NCEI)

  - Record high annual temperatures over land surfaces were measured across parts of central Europe, Asia, Australia, southern Africa, Madagascar, New Zealand, North America, and eastern South America. No land areas were record cold for the year.
  - The annual average temperature departure from average for South America, Europe, Africa, Asia and Oceania ranked among their three highest yearly temperatures on record. Of note, Oceania had its warmest year on record at 2.52°F (1.40°C) above average. Overall, Oceania's annual temperature has increased at an average rate of +0.22°F (+0.12°C) per decade since 1910; it has almost doubled to +0.40°F (+0.22°C) since 1981.

- <u>Global sea surface temperature</u>: The 2019 globally averaged sea surface temperature was also the second highest on record, with a temperature departure from average of 1.39°F (0.77°C) above the 20th century average. Only 2016 was warmer at 1.42°F (0.79°C).

- Record high sea surface temperatures were observed across parts of all oceans, specifically, parts of the North and South Atlantic Ocean, the western Indian Ocean, and northern, western and southwestern Pacific Ocean. No ocean areas were record cold for the year.

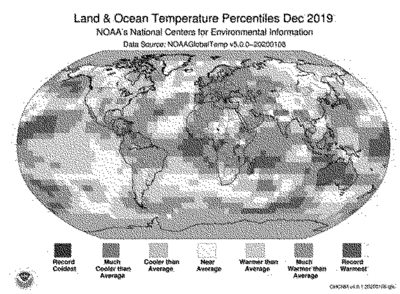
- Global ocean heat content: The upper ocean heat content, which addresses the amount of heat stored in the 0-2000 meters depth of the ocean, was the largest on record.

Snow and Sea Ice Information

- Northern Hemisphere snow cover: According to NOAA data analyzed by the Rutgers Global Snow Lab, the average annual Northern Hemisphere snow cover extent for 2019 was 9.57 million square miles. This was close to average and the 17th smallest annual snow cover extent in the 1967-2019 record.
- Arctic sea ice extent: Recent trends in the decline of Arctic sea ice extent continued in 2019. The monthly Arctic sea ice extent was record or near-record low from April through August, as well as October and November 2019. When averaging monthly data from the National Snow and Ice Data Center, the average annual sea ice extent in the Arctic was approximately 3.94 million square miles and the second smallest annual average sea ice extent in the 1979-2019 record. Only the year 2016 was smaller by about 10,000 square miles. The last four years (2016-19) have the smallest annual sea ice extent in the 41-year record.
- Antarctic sea ice extent: The annual Antarctic sea ice extent was 4.16 million square miles. This was also the second smallest annually averaged value on record, about 30,000 square miles larger than the record small Antarctic sea ice extent set in 2017. The months of May through July had record-low sea ice extent during 2019, while January, March and November had near-record low extents.

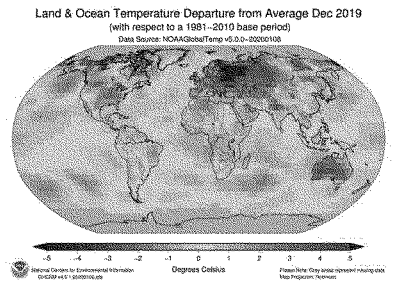
December 2019 Global Climate Highlights

- Global land and ocean surface temperature: For December, the average temperature across global land and ocean surfaces was 1.89°F (1.05°C) above the 20th century average. This value was the second highest departure from average for December in the 1880-2019 record. Only December 2015 (+2.09°F / +1.16°C) was warmer. This was also the eighth highest global land and ocean monthly temperature departure from average for any month on record (1,680 months). The 10 highest monthly temperature departures from average have all occurred since 2015, and all have a temperature departure from average above 1.80°F (1.00°C).



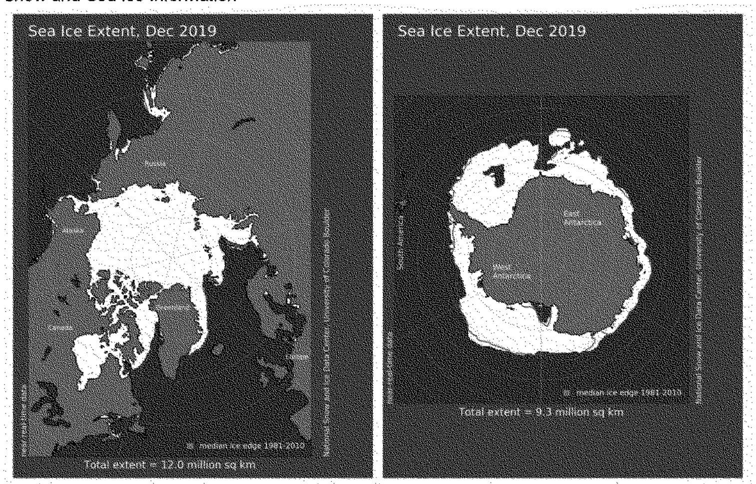
December 2019 Global Average Temperature Percentiles Map (Credit: NOAA NCEI)

- Global land surface temperature: For December, the globally averaged land surface temperature was 3.22°F (1.79°C) above the 20th century average - the second warmest December in the 1880-2019 record, behind December 2015 (+3.58°F / +1.99°C).
- Global ocean surface temperature: The December 2019 globally averaged sea surface temperature was 1.39°F (0.77°C) above the 20th century average. This was also the second highest temperature departure from average for December in the 140-year record. The record-warm December took place in 2015 (+1.53°F / +0.85°C).



December 2019 Global Temperature Departure from Average Map (Credit: NOAA NCEI)

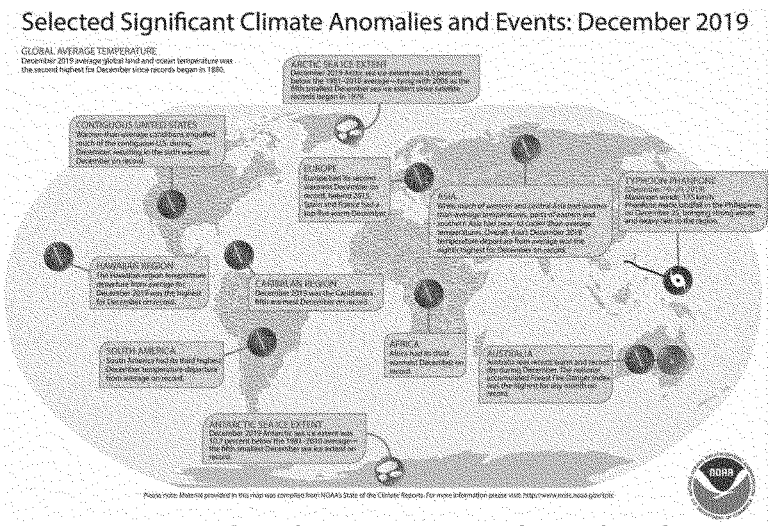
Snow and Sea Ice Information



December 2019 Arctic and Antarctic Sea Ice Extent Maps (Credit: NOAA NCEI)

- Northern Hemisphere snow cover: According to data from NOAA analyzed by the Rutgers Global Snow Lab, the Northern Hemisphere snow cover extent during December was 16.78 million square miles, which is 200,000 square miles below the 1981-2010 average. This was the 19th smallest December value in the 54-year record.
- Arctic sea ice extent: The average Arctic sea ice extent for December was 4.61 million square miles, according to analysis by the National Snow and Ice Data Center based on data from NOAA and NASA. This value was 344,000 square miles (6.9 percent) smaller than the 1981-2010 average and tied with 2006 as the fifth smallest December sea ice extent since records began in 1979.
- Antarctic sea ice extent: Antarctic sea ice extent during December was 3.59 million square miles, according to analysis by the National Snow and Ice Data Center. This value is

430,000 square miles (10.7 percent) smaller than the 1981-2010 average and also the fifth smallest December extent on record.



December 2019 Global Significant Events Map (Credit: NOAA NCEI)

For More Information

This summary, developed by scientists at NOAA National Centers for Environmental Information, is part of the suite of climate services NOAA provides to government, business, academia and the public to support informed decision-making.

For a more complete summary of climate conditions and events, see our 2019 Annual Global Climate Report.

NOAA.gov Highlight:
https://www.noaa.gov/news/2019-was-2nd-hottest-year-on-record-for-earth-say-noaa-nasa

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SUMMARY SUBMITTED BY DR. RICHARD MURRAY

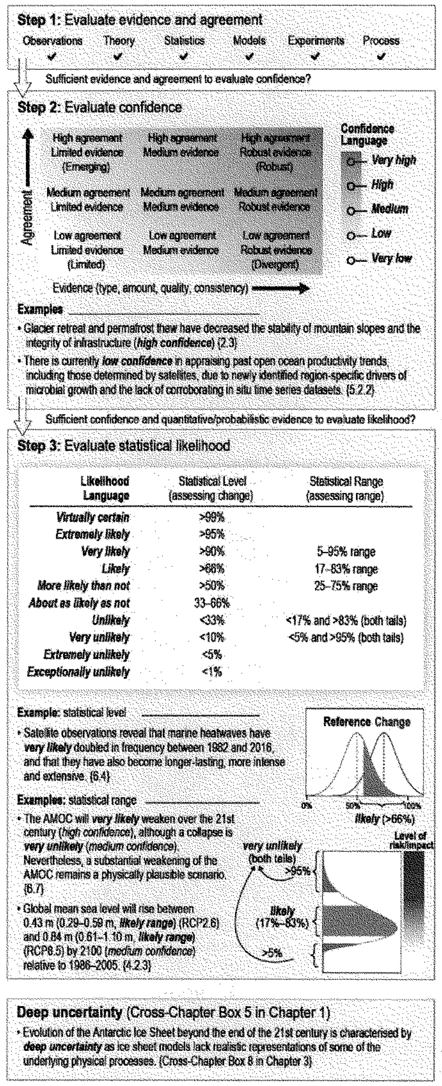
IPCC Special Report on the Ocean and Cryosphere in a Changing Climate
Summary for Policymakers
Key Findings
https://www.ipcc.ch/srocc/chapter/summary-for-policymakers/

The importance of the ocean and cryosphere for people
All people on Earth depend directly or indirectly on the ocean and cryosphere. The global ocean covers 71% of the Earth surface and contains about 97% of the Earth's water. The cryosphere refers to frozen components of the Earth system.

Around 10% of Earth's land area is covered by glaciers or ice sheets. The ocean and cryosphere support unique habitats, and are interconnected with other components of the climate system through global exchange of water, energy and carbon. The projected responses of the ocean and cryosphere to past and current human-induced greenhouse gas emissions and ongoing global warming include climate feedbacks, changes over decades to millennia that cannot be avoided, thresholds of abrupt change, and irreversibility.

Human communities in close connection with coastal environments, small islands (including Small Island Developing States, SIDS), polar areas and high mountains7 are particularly exposed to ocean and cryosphere change, such as sea level rise, extreme sea level and shrinking cryosphere. Other communities further from the coast are also exposed to changes in the ocean, such as through extreme weather events. Today, around 4 million people live permanently in the Arctic region, of whom 10% are Indigenous. The low-lying coastal zone8 is currently home to around 680 million people (nearly 10% of the 2010 global population), projected to reach more than one billion by 2050. SIDS are home to 65 million people. Around 670 million people (nearly 10% of the 2010 global population), including Indigenous peoples, live in high mountain regions in all continents except Antarctica. In high mountain regions, population is projected to reach between 740 and 840 million by 2050 (about 8.4–8.7% of the projected global population).

In addition to their role within the climate system, such as the uptake and redistribution of natural and anthropogenic carbon dioxide (CO2) and heat, as well as ecosystem support, services provided to people by the ocean and/or cryosphere include food and water supply, renewable energy, and benefits for health and well-being, cultural values, tourism, trade, and transport. The state of the ocean and cryosphere interacts with each aspect of sustainability reflected in the United Nations Sustainable Development Goals (SDGs).



All of the statements in the Special Report are assigned a quantitative statement of confidence or likelihood. This schematic demonstrates the IPCC usage of this calibrated language, with examples of confidence and likelihood statements from the *Special Report on the Ocean and Cryosphere in a Changing Climate*. More information is available in Chapter 1, Section 9.2.

A. Observed Changes and Impacts (Ecosystems and People)

Observed Physical Changes
A1. Over the last decades, global warming has led to widespread shrinking of the cryosphere, with mass loss from ice sheets and glaciers (very high confidence), reductions in snow cover (high confidence) and Arctic sea ice extent and thickness (very high confidence), and increased permafrost temperature (very high confidence).

A2. It is virtually certain that the global ocean has warmed unabated since 1970 and has taken up more than 90% of the excess heat in the climate system (high confidence). Since 1993, the rate of ocean warming has more than doubled (likely). Marine heatwaves have very likely doubled in frequency since 1982 and are increasing in intensity (very high confidence). By absorbing more CO2, the ocean has undergone increasing surface acidification (virtually certain). A loss of oxygen has occurred from the surface to 1000 m (medium confidence).

A3. Global mean sea level (GMSL) is rising, with acceleration in recent decades due to increasing rates of ice loss from the Greenland and Antarctic ice sheets (very high confidence), as well as continued glacier mass loss and ocean thermal expansion. Increases in tropical cyclone winds and rainfall, and increases in extreme waves, combined with relative sea level rise, exacerbate extreme sea level events and coastal hazards (high confidence).

Observed Impacts on Ecosystems
A4. Cryospheric and associated hydrological changes have impacted terrestrial and freshwater species and ecosystems in high mountain and polar regions through the appearance of land previously covered by ice, changes in snow cover, and thawing permafrost. These changes have contributed to changing the seasonal activities, abundance and distribution of ecologically, culturally, and economically important plant and animal species, ecological disturbances, and ecosystem functioning. (high confidence)

A5. Since about 1950 many marine species across various groups have undergone shifts in geographical range and seasonal activities in response to ocean warming, sea ice change and biogeochemical changes, such as oxygen loss, to their habitats (high confidence). This has resulted in shifts in species composition, abundance and biomass production of ecosystems, from the equator to the poles. Altered interactions between species have caused cascading impacts on ecosystem structure and functioning (medium confidence). In some marine ecosystems species are impacted by both the effects of fishing and climate changes (medium confidence).

A6. Coastal ecosystems are affected by ocean warming, including intensified marine heatwaves, acidification, loss of oxygen, salinity intrusion and sea level rise, in combination with adverse effects from human activities on ocean and land (high confidence). Impacts are already observed on habitat area and biodiversity, as well as ecosystem functioning and services (high confidence).

Observed impacts on People and Ecosystem Services

A7. Since the mid-20th century, the shrinking cryosphere in the Arctic and high-mountain areas has led to predominantly negative impacts on food security, water resources, water quality, livelihoods, health and well-being, infrastructure, transportation, tourism and recreation, as well as culture of human societies, particularly for Indigenous peoples (high confidence). Costs and benefits have been unequally distributed across populations and regions. Adaptation efforts have benefited from the inclusion of Indigenous knowledge and local knowledge (high confidence).

A8. Changes in the ocean have impacted marine ecosystems and ecosystem services with regionally diverse outcomes, challenging their governance (high confidence). Both positive and negative impacts result for food security through fisheries (medium confidence), local cultures and livelihoods (medium confidence), and tourism and recreation (medium confidence). The impacts on ecosystem services have negative consequences for health and well-being (medium confidence), and for Indigenous peoples and local communities dependent on fisheries (high confidence).

A9. Coastal communities are exposed to multiple climate-related hazards, including tropical cyclones, extreme sea levels and flooding, marine heatwaves, sea ice loss, and permafrost thaw (high confidence). A diversity of responses has been implemented worldwide, mostly after extreme events, but also some in anticipation of future sea level rise, e.g., in the case of large infrastructure.

B. Projected Physical Changes

Projected Physical Changes

B1. Global-scale glacier mass loss, permafrost thaw, and decline in snow cover and Arctic sea ice extent are projected to continue in the near-term (2031–2050) due to surface air temperature increases (high confidence), with unavoidable consequences for river runoff and local hazards (high confidence). The Greenland and Antarctic Ice Sheets are projected to lose mass at an increasing rate throughout the 21st century and beyond (high confidence). The rates and magnitudes of these cryospheric changes are projected to increase further in the second half of the 21st century in a high greenhouse gas emissions scenario (high confidence). Strong reductions in greenhouse gas emissions in the coming decades are projected to reduce further changes after 2050 (high confidence).

B2. Over the 21st century, the ocean is projected to transition to unprecedented conditions with increased temperatures (virtually certain), greater upper ocean stratification (very likely), further acidification (virtually certain), oxygen decline (medium confidence), and altered net primary production (low confidence). Marine heatwaves (very high confidence) and extreme El Niño and La Niña events (medium confidence) are projected to become more frequent. The Atlantic Meridional Overturning Circulation (AMOC) is projected to weaken (very likely). The rates and magnitudes of these changes will be smaller under scenarios with low greenhouse gas emissions (very likely).

B3. Sea level continues to rise at an increasing rate. Extreme sea level events that are historically rare (once per century in the recent past) are projected to occur frequently (at least once per year) at many locations by 2050 in all RCP scenarios, especially in tropical regions (high confidence). The increasing frequency of high water levels can have severe impacts in many locations depending on exposure (high confidence). Sea level rise is projected to continue beyond 2100 in all RCP scenarios. For a high emissions scenario (RCP8.5), projections of global sea level rise by 2100 are greater than in AR5 due to a larger contribution from the Antarctic Ice Sheet (medium confidence). In coming centuries under RCP8.5, sea level rise is projected to exceed rates of several centimetres per year resulting in multi-metre rise (medium confidence), while for RCP2.6 sea level rise is projected to be limited to around 1m in 2300 (low confidence). Extreme sea levels and coastal hazards will be exacerbated by projected increases in tropical cyclone intensity and precipitation (high confidence). Projected changes in waves and tides vary locally in whether they amplify or ameliorate these hazards (medium confidence).

Projected Risks for Ecosystems

B.4 Future land cryosphere changes will continue to alter terrestrial and freshwater ecosystems in high-mountain and polar regions with major shifts in species distributions resulting in changes in ecosystem structure and functioning, and eventual loss of globally unique biodiversity (medium confidence). Wildfire is projected to increase significantly for the rest of this century across most tundra and boreal regions, and also in some mountain regions (medium confidence).

B5. A decrease in global biomass of marine animal communities, their production, and fisheries catch potential, and a shift in species composition are projected over the 21st century in ocean ecosystems from the surface to the deep seafloor under all emission scenarios (medium confidence). The rate and magnitude of decline are projected to be highest in the tropics (high confidence), whereas impacts remain diverse in polar regions (medium confidence) and increase for high emission scenarios. Ocean acidification (medium confidence), oxygen loss (medium confidence) and reduced sea ice extent (medium confidence) as well as non-climatic human activities (medium confidence) have the potential to exacerbate these warming-induced ecosystem impacts.

B6. Risks of severe impacts on biodiversity, structure and function of coastal ecosystems are projected to be higher for elevated temperatures under high compared to low emissions scenarios in the 21st century and beyond. Projected ecosystem responses include losses of species habitat and diversity, and degradation of ecosystem functions. The capacity of organisms and ecosystems to adjust and adapt is higher at lower emissions scenarios (high confidence). For sensitive ecosystems such as seagrass meadows and kelp forests, high risks are projected if global warming exceeds 2°C above pre-industrial temperature, combined with other climate-related hazards (high confidence). Warm water corals are at high risk already and are projected to transition to very high risk even if global warming is limited to 1.5°C (very high confidence).

Projected Risks for People and Ecosystem Services

B7. Future cryosphere changes on land are projected to affect water resources and their uses, such as hydropower (high confidence) and irrigated agriculture in and downstream of high-mountain areas (medium confidence), as well as livelihoods in the Arctic (medium confidence). Changes in floods, avalanches, landslides, and ground destabilization are projected to increase risk for infrastructure, cultural, tourism, and recreational assets (medium confidence).

B8. Future shifts in fish distribution and decreases in their abundance and fisheries catch potential due to climate change are projected to affect income, livelihoods, and food security of marine resource-dependent communities (medium confidence). Long-term loss and degradation of marine ecosystems compromises the ocean's role in cultural, recreational, and intrinsic values important for human identity and well-being (medium confidence).

B9. Increased mean and extreme sea level, alongside ocean warming and acidification, are projected to exacerbate risks for human communities in low-lying coastal areas (high confidence). In Arctic human communities without rapid land uplift, and in urban atoll islands, risks are projected to be moderate to high even under a low emissions scenario (RCP2.6) (medium confidence), including reaching adaptation limits (high confidence). Under a high emissions scenario (RCP8.5), delta regions and resource rich coastal cities are projected to experience moderate to high risk levels after 2050 under current adaptation (medium confidence). Ambitious adaptation including transformative governance is expected to reduce risk (high confidence), but with context-specific benefits.

C. Implementing Responses to Ocean and Cryosphere Change

Challenges

C1. Impacts of climate-related changes in the ocean and cryosphere increasingly challenge current governance efforts to develop and implement adaptation responses from local to global scales, and in some cases pushing them to their limits. People with the highest exposure and vulnerability are often those with lowest capacity to respond (high confidence).

Strengthening Response Options

C.2 The far-reaching services and options provided by ocean and cryosphere-related ecosystems can be supported by protection, restoration, precautionary ecosystem-based management of renewable resource use, and the reduction of pollution and other stressors. Integrated water management and ecosystem-based adaptation approaches lower climate risks locally and provide multiple societal benefits. However, ecological, financial, institutional and governance constraints for such actions exist, and in many contexts ecosystem-based adaptation will only be effective under the lowest levels of warming.

C3. Coastal communities face challenging choices in crafting context-specific and integrated responses to sea level rise that balance costs, benefits and trade-offs of available options and that can be adjusted over time (high confidence). All types of options, including protection, accommodation, ecosystem-based adaptation, coastal advance and retreat, wherever possible, can play important roles in such integrated responses (high confidence).

Enabling Conditions

C4. Enabling climate resilience and sustainable development depends critically on urgent and ambitious emissions reductions coupled with coordinated sustained and increasingly ambitious adaptation actions (very high confidence). Key enablers for implementing effective responses to climate-related changes in the ocean and cryosphere include intensifying cooperation and coordination among governing authorities across spatial scales and planning horizons. Education and climate literacy, monitoring and forecasting, use of all available knowledge sources, sharing of data, information and knowledge, finance, addressing social vulnerability and equity, and institutional support are also essential. Such investments enable capacity-building, social learning, and participation in context-specific adaptation, as well as the negotiation of trade-offs and realisation of co-benefits in reducing short-term risks and building long-term resilience and sustainability. (high confidence) This report reflects the state of science for ocean and cryosphere for low levels of global warming (1.5°C), as also assessed in earlier IPCC and IPBES reports.

National Academies of Science
Division on Earth and Life Sciences
Ocean Studies Board
Sustaining Ocean Observations to Understand Future Changes in Earth's Climate (2017)
https://www.nap.edu/download/24919

The goals of the study included considerations of what observations are most critical, the specifications for those observations, the present approaches to sustained ocean observing, and of the challenges to long-term ocean observing. A second stage of the study is scheduled to start later this month where new models or approaches to sustained ocean observing will be pursued.

What Are Ocean Observations for Climate?

- Ocean observations are made using both satellite and in situ (located within the water) instrumentation.
- In situ (in water) observations are carried out using fixed and mobile platforms such as tide gauges, data buoys, moorings, ship-based observations, profiling floats, ocean gliders, and surface drifters.
- Priority ocean variables observed for climate are sea state, ocean surface stress, sea ice, sea surface height, sea surface temperature, subsurface temperature, surface currents, subsurface currents, sea surface salinity, subsurface salinity, ocean surface heat flux, and dissolved inorganic carbon.
- The ocean observing enterprise is an end-to-end system built on engineering, operations, data management, information products, and the associated human capabilities, which are supported by the planning and governance by international coordination entities and by regional and national agencies.

Value of Sustained Observations

With the accumulation of greenhouse gases in the atmosphere, notably CO2 from fossil fuel combustion, the Earth's climate is now changing more rapidly than at any time since the advent of human societies. Society will increasingly face complex decisions about how to mitigate the adverse impacts of climate change such as droughts, sea-level rise, ocean acidification, species loss, changes to growing seasons, and stronger and possibly more frequent storms. To make informed decisions, policy makers will need information that depends on understanding the dynamics of the planet's climate system. Because these dynamics will evolve as the climate warms, the ability to anticipate and predict future climate change will depend on ongoing observations of key climate parameters to tune and enhance models. Observations play a foundational role in documenting the state and variability of components of the climate system and facilitating climate prediction and scenario development. Regular and consistent collection of ocean observations over decades to centuries would monitor the Earth's main reservoirs of heat, CO2, and water and provides a critical record of long-term change and variability over multiple timescales. Sustained high-quality observations are also needed to test and improve climate models, which provide insights into the future climate system. With knowledge gained through these observations and models, more informed decisions can be made about how to respond and adapt to the impacts of climate change on national security, the economy, and society. Sustained observations of environmental variables are thus essential to advance understanding of the state of the climate system now and in the future.

Study Task and Approach

The committee was charged with considering processes for identifying priority ocean observations that will improve understanding of the Earth's climate processes, and the challenges associated with sustaining these observations over long time frames, and approaches for overcoming these challenges. The committee considered the priority variables that are most needed to address the ocean's role in climate while recognizing that there are important ocean variables to observe outside of the scope of the study.

Heat, Carbon, and Fresh Water Budgets

This report identifies three distinct global budgets that help define critical observations for understanding climate: heat, carbon, and fresh water. These were selected because of the central role the ocean plays in each and for their ability to inform climate model projections and detect changes within the climate system. Ocean observations have contributed to vital insights into changes in these budgets and informed understanding of other related ocean changes, such as sea-level rise. Uninterrupted time series of observations are required to distinguish natural variability of ocean processes from changing long-term climate trends. Although ocean general circulation models employ data assimilation methods to estimate the state of the ocean and provide quantitative estimates of how well the observations constrain these budgets, closing these budgets will require extension of ocean climate observations to the full depth of the ocean and into poorly sampled regions such as the polar seas. Additional research will be needed to develop the advanced observing capabilities needed to quantify the full suite of processes contributing to each budget.

Heat Budget

Ocean warming accounts for about 90 percent of the net global surface heat gain. Hence, accurate estimates of ocean heat content provide a fundamental index of the

present climate system that also will be a determinant of future global surface warming as ocean circulation returns heat stored in the depths to the sea surface. Because heat absorbed by surface ocean waters is transported laterally and vertically through the depth layers and basins of the ocean via mixing and currents, there is no single variable that can be measured to determine ocean
warming.

Carbon Budget

About 30 percent of the CO2 released by human activities has been absorbed by the ocean, reducing the amount in the atmosphere and the associated greenhouse effect. However, dissolved CO2 becomes a weak acid that lowers the pH of sea water, a phenomenon termed ocean acidification, which will limit the capacity of the ocean to absorb more CO2 in the future and can have negative effects on marine life.

Fresh Water Budget

The fresh water budget is important for understanding changes in the salinity of the ocean, a parameter that influences ocean circulation due to stratification, and therefore heat and carbon exchange between the ocean surface and the atmosphere.

Sea Level Reflects Heat and Budgets

Sea-level rise, one of the leading indicators of a warming climate, will have major impacts on coastal communities and economies, affecting shipping, national and homeland security, tourism, and other valuable societal activities. The ocean heat content provides estimates of rates of thermosteric sea-level rise, the rise in sea level caused by the expansion of the ocean as it absorbs increasing amounts of heat. The net fresh water input to the ocean, which increases when higher temperatures cause land ice to melt and run off into the ocean, is the other major contribution. To assess these components of the heat and fresh water budgets, in situ measurements of temperature and salinity are needed throughout the water column. Moreover, ocean current observations are required to evaluate the transport of heat and salt and their effects on regional sea level. Refining the calculations of these budgets based on a comprehensive set of in situ measurements will advance our understanding of global and regional sea-level change, which is essential for assessing risks to coastal communities and infrastructure in the United States, and to low-lying regions worldwide.

REPORT FINDINGS

Progress Achieved by Ocean Observations

Finding: The current ocean observing system has made significant contributions to better understanding the ocean's role in the Earth system, including its heat, carbon, and fresh water budgets, and to better understanding global and regional sea-level change. Sustaining, optimizing, and increasing ocean observing capability will further improve understanding of the ocean's role in climate.

Benefits of Ocean Observations Beyond Climate

Finding: The ocean observing system contributes not only to our understanding of climate variability and change, but also to a wide variety of other services including weather and seasonal-to-interannual forecasting, living marine resource management, and marine navigation. This understanding of climate variability and change and other services underpins national defense, economic, and social policy decisions.

Observing System Operations

Finding: Direct scientific involvement in sustained observing programs, from design to implementation to analysis, synthesis, and publication, ensures that the ocean observing system will be robust in terms of data quality, incorporation of new methods and technologies, and scientific analyses; all are essential elements for realizing the value of long-term, sustained observations.

The Global Ocean Observing System

Finding: The GOOS efforts are effective at promoting international cooperation to sustain the ocean climate observing system. Its guiding document, the Framework for Ocean Observing, and the associated procedures for establishing priority observation—the Essential Ocean Variables—are constructive for defining ongoing requirements (precision, frequency, spatial resolution) for sustained ocean observations and provide a solid foundation for selecting and prioritizing ocean variables for sustained observing.

Finding: Opportunities exist to increase the spatial coverage and multidisciplinary nature of sustained ocean observations through U.S./international (either bilateral or multilateral) coordination and sharing of resources.

Finding: Capacity building enhances international support for the sustained ocean observing system and is valuable for increasing international use of the information and sharing of observing responsibilities.

National Coordination, Planning, and Funding Challenge

Finding: The continuity of ocean observations is essential for gaining an accurate understanding of the climate. Funding mechanisms that rely on annual budget approval or short-term grants may result in discontinuity of ocean climate measurements, reducing the value of the observations made to date and in the future.

Finding: To avoid data gaps and ensure the required data quality and the accessibility of the data for monitoring climate over decades, ocean observing initiatives will need to plan for the end-to-end scope of expenses associated with observing programs, including appropriate logistical planning.

Finding: The absence of an overarching long-term (e.g., 10-year) national plan with associated resource commitments and lack of strong leadership presents a challenge for sustaining U.S. contributions to ocean observing, by inhibiting effective coordination and multiyear investments in the many components of the observing system.

New Technology Challenge

The limited investment in advancing technological capabilities is a challenge that, if addressed, will yield significant returns over the lifetime of sustained observing platforms through development of more robust and efficient sensors and platforms and through the maturation of observing methods to address existing and new scientific challenges.

Conclusion on Technology: Declining investments have slowed the development of new technology, which is proven to expand the capability, the efficiency, and therefore, the capacity of the observing system. If addressed, this investment will yield significant returns over the lifetime of sustained observing platforms through development of more robust and efficient sensors and platforms. Some philanthropic efforts have in part filled this gap and the OCP could encourage more support there.

Research Fleet Challenge

Research vessels are indispensable to the ocean observing system, providing direct observations and deployments of moored and drifting instruments. Ships require long-term planning and investment, and maintenance of a capable fleet of research vessels is an essential component of the U.S. effort to sustain ocean observing.

Conclusion on the Research Fleet: While new technology holds promise for access to the ocean, a capable fleet of research vessels, including those with global reach, is essential to sustaining the U.S. contribution to ocean observing.

Finding: The decreasing number of global- and ocean-class research vessels is creating a shortfall in the infrastructure required for sampling the global ocean and expanding collection into poorly sampled regions such as the polar seas.

The Challenge of Short-Term Funding

Finding: The continuity of ocean observations is essential for gaining an accurate understanding of the climate. Funding mechanisms that rely on annual budget approval or short-term grants may result in discontinuity of ocean climate measurements, reducing the value of the observations made to date and in the future.

Workforce Challenge

Finding: Direct scientific involvement in sustained observing programs, from design to implementation to analysis, synthesis, and publication, ensures that the ocean observing system will be robust in terms of data quality, incorporation of new methods and technologies, and scientific analyses; all are essential elements for realizing the value of long-term, sustained observations. The long-term investment required to develop and sustain the necessary expert workforce of the future is a challenge due to limited professional rewards or career incentives at research institutions and laboratories to ensure intergenerational succession of scientists, engineers, and technical staff.

Nonfederal Players

Finding: Raising awareness of the importance and value of sustained ocean climate observations could increase support for the observing system from multiple sectors, including philanthropic organizations.

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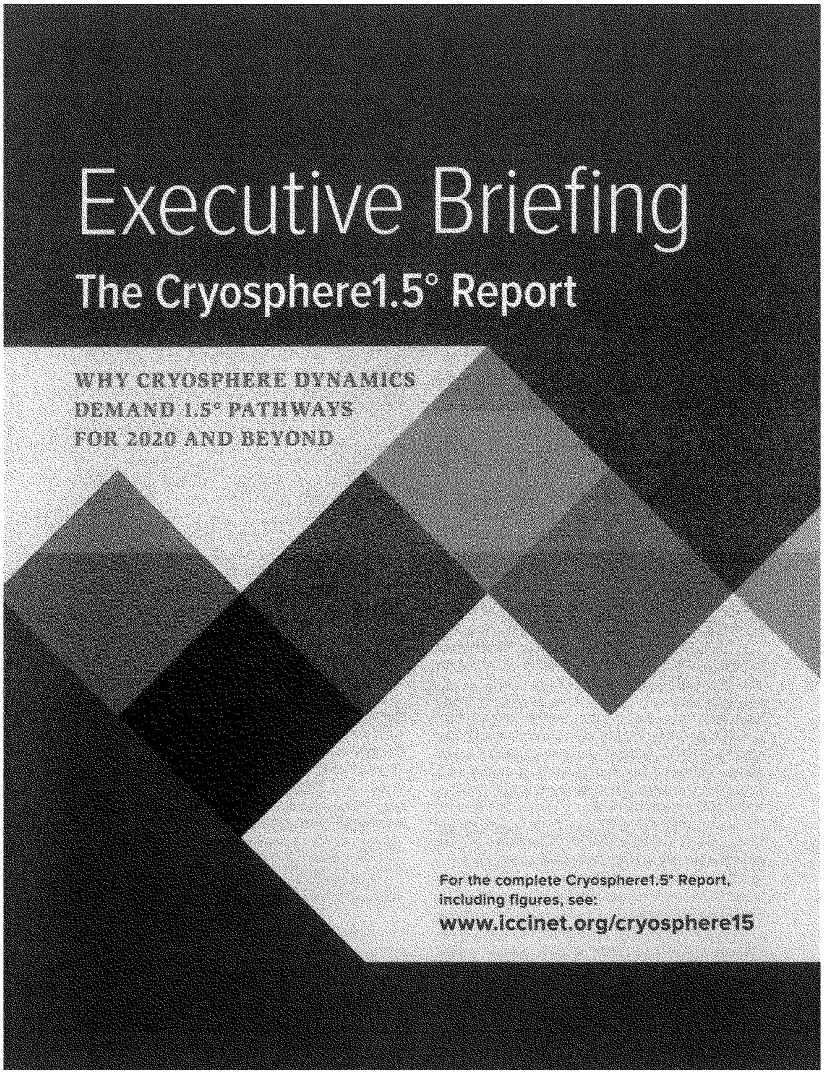
EXECUTIVE SUMMARY SUBMITTED BY DR. HEIDI STELTZER



Preface

Over the next year, governments face the most consequential decision collectively made in the history of humanity: whether to take concrete steps to keep the planet below 1.5°C warming, or make the decision – either explicitly, or de facto through inaction – to force the planet's temperatures higher.

These 2020 NDCs, or Nationally Determined Contributions will mostly cover the years up to 2030, following the Paris Agreement NDCs in 2015 that mostly covered 2020–2025. This decade is what the IPCC Special Report on 1.5 Degrees of Warming (SR1.5) determined as critical to stay below the 1.5° level. So far, not only do combined NDCs to-date risk our reaching 3°C or more in 80 years: present emission trends have us breaching 4°C within the lifetimes of many children born today. Emissions have in other words, continued unchecked on a "business as usual" scenario despite the signing of the Paris Agreement four years ago.

Since Paris, other political and economic forces have caused a growing number of decision makers to place their attention elsewhere, from populist domestic politics to destructive international conflicts. This Report, reviewed by over 30 IPCC and other leading scientists, is an attempt to bring attention back to what inevitably will result if attention remains so diverted, all because of the freezing point of water.

The cryosphere – snow and ice regions – is amazingly sensitive to small changes in temperature: at root, the slight temperature difference between solid frozen ice, and liquid water. This principle holds for an ice cube taken from the freezer, or a mountain glacier or great polar ice sheet: once temperature exceeds 0°C/32°F, it melts. And in Earth's past, the difference between the 1°C above pre-industrial temperatures where we are today, and 2°C has been very different planetary states, including the difference between a few meters of sea-level rise, to well above 20 meters.

Glaciers, snow, permafrost and sea ice all make up the cryosphere: slow to react to warmer temperatures, but even slower to return once temperatures fall again. A decision to allow temperatures to go above 1.5°C – let alone 2.0°C or above – inevitably will cause a change in cryosphere that will in turn, change the Earth to one which has never seen human existence.

The summaries in this Cryosphere1.5 Report, taken from the IPCC SR1.5 and Special Report on the Oceans and Cryosphere (SROCC) and other published research, confirm this physical reality that at some point in the gradient above 1.5°C, processes will be set in motion that cannot be halted or easily reversed, in some cases not even if temperatures return to pre-industrial. This is why policy decisions in the coming years will determine the future state of the Earth for centuries and generations to come. Never has a single generation held the future of so many coming generations, species and ecosystems in its hands. Cryosphere climate change is not like air or water pollution, where the impacts remain local and from which ecosystems largely can be restored. Cryosphere climate change, driven by the physical law of water's response to 0°C, is different. Slow to manifest itself, once triggered it inevitably forces the Earth's climate system into a new state, one that most scientists believe has not existed for 65 million years.

This future however is neither defined, nor hopeless. Instead, pathways to the needed lower emissions levels not only exist, but were very well-defined in the SR1.5 as physically, technologically, and economically feasible.

This is why decision makers in the span of the next year will make the most consequential decision in the history of humanity, let alone the planet. As they – as you – make these decisions, it is important that you know what they will mean. Will the Earth address the cryosphere crisis, or let it fail because other, more short-term issues took precedence?

The choice is ours. The cryosphere cares about nothing but the melting point of water.

Christiana Figueres
Former UNFCCC Executive Secretary
Co-founder, Global Optimism Ltd.

Jean-Pascal van Ypersele,
Former IPCC Vice-chair
Professor UCLouvain, Belgium

Executive Summary

AVERTING A MUCH-CHANGED EARTH

Decisionmakers today face with a choice between unprecedented but necessary policies and actions that will hold the world below 1.5°C, or take a slower, seemingly more "prudent" and "realistic" path towards 2°C, 3°C or above. The IPCC Special Report on 1.5 Degrees of Warming (SR1.5) laid out those choices in stark and clear terms upon its release in October 2018. Nearly a year later, the Special Report on Oceans and Cryosphere (SROCC) summarized the current status and future of the water and ice parts of the world. In the cryosphere – portions of the globe seasonally or permanently in a frozen state – it detailed a world undergoing rapid and in some respects, irreversible changes, all tied to the freezing point of water; or rather, the melting point of ice.

This Report, authored and reviewed by over 40 IPCC and other cryosphere scientists, combines the findings of both the SR1.5, and SROCC, plus published studies since. Its inevitable, science-based conclusion: failure to choose policies keeping the world below 1.5° is neither measured nor economically prudent. Instead, it will result in a cascading series of disasters; not only for people living this century, but even more so for the generations that follow. Warming above 1.5° will have many impacts, but the physical realities of changes in cryosphere alone will drive much of what follows.

This is because the gradient between today's 1°C above pre-industrial temperatures, to 1.5° and 2°C and above, represents a drastic and on human timescales, essentially permanent shift in the state of our planet *because of the cryosphere response*. The Report's main findings:

Ice Sheets and Sea-Level Rise

We see far greater risk of massive irreversible sea-level rise (SLR) at 2°C, on a scale of 12–20 meters or more in the long term. The climate record of the earth over the past few million years is quite clear:

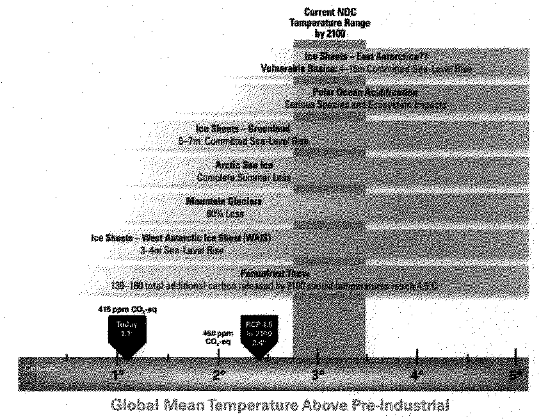
- At today's temperature of 1°C over pre-industrial, we have locked in about 1–3 meters of sea-level rise over the next centuries from loss of mountain glaciers and a portion of the polar ice sheets, even if we could hold temperatures at 1°C.
- Risks rise substantially at 1.5°, with the Earth showing a pattern of 6–9 meters compared to today when it was this warm in the past; coming from additional loss of Greenland and most of the West Antarctic Ice Sheet (WAIS).
- 2°C however shows a much sharper rise: between 12–20 meters as the new global sea level, locked in over millennia. This is because both the WAIS and Greenland melt nearly completely at a sustained 2°C; with vulnerable portions of East Antarctica also posing a threat; and up to 25 meters occurring between 2° and 3°C.
- Most seriously, periods of time well in excess of 2°C – especially if we reach 3°C, 4°C or more, which is our current emissions pathway – increase the risk, speed and potential inevitability of the above changes. The rate of change can itself become a risk: at the end of the last Ice Age, sea levels rose by up to 4 cm per year, and 12–14 meters in the space of a few centuries.

The good news: these processes, especially the collapse of the West Antarctic Ice Sheet can be slowed if temperatures remain close to 1.5°, allowing far more time for communities to adapt to the rising seas. Much of the WAIS may have passed a threshold of collapse sometime between 2010 and 2015, at around 0.8°C; but at lower temperatures such as 1.5°C, this collapse can be slowed to perhaps thousands of years, rather than (in the worst projections) just a few centuries. Even at today's 1°C, Greenland's ice loss has doubled in the past 20 years; and Antarctica's has tripled.

Mountain Glaciers and Snow

Few glaciers near the Equator, such as the northern Andes and East Africa can survive even today's 1°C. Some of these were shrinking anyway after the last ice age; but global warming has speeded their disappearance by many centuries. Glaciers and snow in the northern Andes provided a reliable seasonal source of water, and their loss especially will impact rural populations in Peru and Chile.

FIGURE 5-1. **Cryosphere Dynamics and Temperature**



Approximate temperature ranges at which five important cryosphere dynamics or "thresholds" may be triggered, some irreversibly on human timescales, based on updated observations and models.

Mid-latitude glaciers and snow in the Alps, southern Andes/Patagonia, Iceland, Scandinavia, New Zealand and North American Rockies can survive at 1.5°, but these glaciers will disappear almost entirely at 2°C, and snow cover decrease. For these glaciers and mountain snowpack, that half a degree spells the difference between sufficient seasonal water supply, such as in the American West, Tarim and Indus river basins; and water scarcity.

The essential watersheds of the Himalayas/Central Asia at 1.5°C maintain around half to about two-thirds of their ice. At 2°C, much more will be lost, with regional impacts on water supply and increasing political instability, especially as monsoon rains become far more unpredictable at 2°C as well.

Permafrost and Carbon Budgets

Limiting warming to 1.5° rather than 2°C saves 2 million square kilometers of permafrost. Permafrost carbon release (as both methane and CO2) is greater at 2°, especially in "overshoot" scenarios because once thawed, former permafrost irreversibly continues to release carbon for centuries:

- If we can hold temperatures to 1.5°C, cumulative permafrost emissions by 2100 will be about equivalent to those currently from Canada (150–200 Gt CO_2-eq).
- In contrast, by 2°C scientists expect cumulative permafrost emissions as large as those of the EU (220–300 Gt CO_2-eq).
- If temperature exceeds 4°C by the end of the century however, permafrost emissions by 2100 will be as large as those today from major emitters like the United States or China (400–500 Gt CO_2-eq), the same scale as the remaining 1.5° carbon budget.

These permafrost carbon estimates include emissions from the newly-recognized abrupt thaw processes from "thermokarst" lakes and hillsides, which expose deeper frozen carbon previously considered immune from thawing for many more centuries.

The "anthropogenic" carbon budget to reach carbon neutrality and remain within 1.5° of warming must begin to take these "country of Permafrost" emissions into account. Only lower emissions pathways that preserve as much permafrost as possible can minimize this potentially large contribution to future global warming, and the need for future generations to maintain negative emissions efforts to compensate for those from thawed former permafrost.

Sea Ice and Polar Ocean Acidification and Fisheries

At 1.5°C global warming, it is unlikely that Arctic sea ice will melt completely in any given summer; and if it does melt completely, that ice-free period will be brief. In contrast, by 2°C the Arctic Ocean is expected to be ice free in summer for several months. This long ice-free period will warm the Arctic Ocean, feeding back to raise regional air temperatures and accelerating Greenland melt and associated sea level rise; increasing permafrost thaw and associated carbon emissions; and also leading to a decrease in snow cover. All of these will in turn make for faster rates and scale of overall global warming, making efforts to address the problem that much harder.

Many parts of the Arctic ecosystem depend on the existence of thicker, multi-year sea ice. These will likely collapse with the complete disappearance of multi-year ice cover at 2.0°C global warming. This impact is amplified by our observation already today of more frequent ocean "heat waves." Human communities are of course also impacted, especially Arctic indigenous cultures reliant on the reliable presence of sea ice for many thousands of years.

Fish stocks such as cod are much more negatively affected by changes in the polar oceans at 2°C global warming than at 1.5°C global warming. These changes include ocean acidification, warmer and less salty sea water from increased river runoff, glacier melt and ice sheet melt; as well as greater competition from mid-latitude species moving polewards. In contrast, polar species and ecosystems have nowhere further to migrate.

Today's rates of ocean acidification are greater than at any time in 3 million years, and pose an immediate and serious threat in cold polar waters, which absorb CO2 more quickly. The oceans will need 50–70,000 years to return to normal pH levels, a key argument for keeping CO_2 levels as low as possible and against schemes aiming to decrease solar radiation rather than CO_2.

Conclusions

Current rates of warming and CO2 increase have not occurred in the past 60 million years of Earth's geologic history. Most "uncertainties" trend towards greater damage and risk, not less. There is no real geologic precedent for predicting the cryosphere response and its risks.

Overshoot is not an option. The risk of triggering these dynamics irreversibly grows with each tenth of a degree over 1.5°, and especially once we exceed 2°C.

1.5°C remains both possible, and imperative. The SR1.5 made clear that pathways to remain below 1.5° globally remain, but will require immediate and transformative action. Many countries and sub-national stakeholders are moving to answer this call, taking concrete steps towards emissions that if adopted globally, will keep the planet below 1.5°. More countries and actors need to join their ranks and intensify their 2020–2030 reductions to 1.5° levels.

The message is clear: 2°C means a completely unacceptable risk of loss and damage to human society, from cryosphere dynamics alone. We must aim for 1.5°C, and to be frank, to the extent possible plan for a return to 1°C as soon as possible because of the way the cryosphere will respond even at the long-term 1.5° level, through negative emissions measures.

This is an issue of generational justice, and the legacy we leave behind.

Temperatures, "Nationally Determined Contributions" and Carbon Budgets in This Report

To calculate future temperature impacts,[1] scientific studies largely use a set of three greenhouse gas pathways (called RCPs, for "Representative Concentration Pathways") through 2100 that lead to changes in the planet's energy balance, expressed as watts per square meter (W/m^2). So RCP 2.6 results in 2.6 W/m^2, RCP 4.5 leads to 4.5 W/m^2 in 2100, and so on.

These different levels of "climate forcing" translate into certain temperature ranges by 2100. RCP2.6 is used by many scientists and policy makers as a proxy for 1.5°C pathways, but actually overshoots a 1.5°C limit by a bit (see Table below). For the purposes of this report, RCP4.5 is used as a proxy for 2°C; though in the models, RCP4.5 actually results in a temperature above 2°C, reaching about 2.4°C in 2100.

"High emissions" scenarios refer to RCP8.5, the highest level of human emissions considered. Despite the Paris Agreement, emissions today still appear to follow such a "business as usual" pathway, which has the world exceeding 4°C by 2100. Although far above what cryosphere scientists would define as a lower-risk pathway, this report occasionally outlines what scientists project will occur if emissions continue on a high emission, RCP8.5 pathway.

Because the cryosphere in the past has responded most clearly to temperature, much of this report focuses on temperature rather than CO_2 emissions, because changes in Earth's temperature in the past sometimes came from other shifts such as slow changes in the Earth's orbit around, or orientation towards the sun. For polar as well as global ocean acidification, however, CO_2 concentrations are key; and once this CO_2 is absorbed into the ocean and acidification occurs, these more "acidic" waters will persist for tens of thousands of years, as outlined in the Polar Oceans chapter.

In reality, scientists today are quite certain that today's temperature rise does come from human emissions of CO_2; so one way to express human decisions to either continue, or slow down warming is through carbon budgets: the amount of CO_2 and other carbon emissions that can occur before a certain temperature level is breached. The table below lists the remaining range of possible carbon emissions as outlined in the SR1.5. The limit amount – or budget – of carbon emissions related to a specific temperature boundary is especially important as regards the contribution of permafrost emissions due to thaw at higher temperatures, a main focus of the Permafrost chapter. Usually such emissions are not included in carbon budgets, and would need to be added in order to accurately guide mitigation efforts limiting anthropogenic emissions.

Country commitments, or "Nationally Determined Contributions" (NDCs) were first made in connection with the Paris Agreement in 2015, and are scheduled to be updated by COP-26 in November 2020: in most cases, covering the period 2025–2030. Scientists agreed in the IPCC Special Report on 1.5 Degrees of Warming (SR1.5) that 2030 is the outer boundary for remaining on a 1.5°C pathway, which this Report makes clear has become an outer boundary for avoiding the most catastrophic future impacts from cryosphere dynamics. The SR1.5 identified different actions, or "emissions pathways" that will allow the Earth's global mean temperature to remain within 1.5°C. This Report uses the calculations of the Climate Action Tracker (CAT) to evaluate where current NDCs, or climate commitments will take the globe in terms of future temperatures, whether at the country or global level. The CAT is produced by a consortium of European research institutions[1].

SCIENTIFIC REVIEWERS

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TABLE 5-1. **Emissions Pathways, Temperatures and Carbon Budgets**

RCP	T in °C, 2100	Peak T in °C	Peak Emissions Year	Peak PPM	Remaining Carbon from 2018 (Gt CO2-eq)
2.6	1.6	1.6	2020	450	420*
4.5	2.4	3.1	2040	650	1170*
8.5	4.3	8–12+	2100	1250+	N/A

* from SR1.5, Table 2.2. Refers to 1.5°C and 2°C rather than RCP2.6 and 4.5, respectively, both with at least 66% chance with respect to uncertainties in the carbon cycle and in the climate system's response to emissions, but not including the effects of – and uncertainty in – permafrost thawing.

[1] Climate Analytics, NewClimate Institute and Potsdam Institute for Climate Research

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TEXT BOX TEMPERATURES, NDCS AND CARBON BUDGETS

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1 ICE SHEETS

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2 MOUNTAIN GLACIERS AND SNOW

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