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CONCERNING THE STATE OF CLIMATE SCIENCE
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Good morning Chairwoman Johnson, Ranking Member Lucas, and members of the Committee. I am grateful for the invitation to join you today, and for the opportunity to share my perspective on the state of climate science, and why it matters.

My name is Joseph Majkut. I am the director of climate policy at the Niskanen Center, located here in Washington, D.C.[1] The Niskanen Center is nonpartisan 501(c)(3) organization that promotes public policy to advance an open society. We reject ideological dogmatism and argue for a balanced consideration of the need for social justice, civil liberties, individual freedom, and community wellbeing. Our work in climate seeks to promote mainstream understanding of climate science, better characterize the risks of climate change, and support market-based policies to reduce greenhouse gas emissions.

The atmosphere, and the climate it maintains, are a public good. No matter your beliefs about the proper size and scope of government, the reality is that government must act to reduce the risks of climate change, and it already is doing so in several areas. But at present, far too many tons of CO2 are emitted here, and abroad, without sufficient regard to the damages they will cause future generations. In the long term, that will make us worse off.

The responses to this problem do not have to be onerous government regulation and mandates, and they don't have to be hasty. It wouldn't be wise to halt emissions tomorrow or prevent future economic growth, but we could be doing much more to reduce emissions here in the United States beyond the already laudable reductions we've seen in the last 10 years. Congress should pursue new solutions to outpace and underspend the mix of regulations and subsidies that we have today. There is no better innovative force than the private sector, but if you really want energy innovation, you need to show innovators there is a market waiting for them.

For this hearing, we were asked to advise the committee on how recent scientific advances have affected our understanding of the risks of climate change and what society can do to respond to those risks. We were asked to specifically comment on the United Nations Intergovernmental

[1] The Niskanen Center's writing and analysis on climate matters can be found here: https://niskanencenter.org/blog/policies/climate/

Panel on Climate Change's Special Report Global Warming of 1.5C[2] and the 4th National Climate Assessment prepared by the U.S. Global Change Research Program.[3]

I think a fair summary of those reports might go as follows. Climate change is real and global emissions of greenhouse gases are a leading driver of latter-day global warming. The manifestations of that warming are being increasingly observed in climate indices and understood as a factor in weather and climate events. But these are early days, so many of the changes scientists expect are still subtle or even undetectable at high confidence. As climate change continues, more severe and pervasive effects will reveal themselves, causing damages to individuals, ecosystems, and economic harm.

However, halting climate change at the levels being targeted in international agreements, either 1.5 or 2 degrees C, would require significant reductions in global emissions rates to start immediately and proceed quickly. To be consistent with continued economic growth, those reductions will require technological innovations to provide reliable, affordable, and globally-accessible low-carbon energy.

Given where we find ourselves, how should this committee respond in this Congress?

First, the time to talk about solving climate change has passed. The warming that has already occurred is evident and will continue with global emissions. We are managing a chronic condition and we cannot place the whole burden on reducing global emissions. Reducing societal vulnerability and adapting to climate change should be a priority, but is also largely an activity done in the private sector and through local governance. Those efforts can be meaningfully informed through federal support for research into how climate change will affect our communities. The products of that work can be disseminated through social and professional networks, as well as through efforts like the repeating National Climate Assessment. Identifying new research needs and new means of understanding climate risks at all levels of government is valuable.

Second, I think it is prudent for the committee to recognize that the emissions reductions necessary to meet any temperature target, but especially anything approaching 2 or 1.5C, will require substantial technological innovations and a portfolio of low-carbon energy sources. In all likelihood, emissions pathways consistent with a 2C warming limit will involve some form of carbon capture and storage for fossil fuels and 1.5C will necessitate carbon removal technology.[4]

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[2] Intergovernmental Panel on Climate Change: https://www.ipcc.ch/sr15/

[3] United States Global Change Research Program: https://nca2018.globalchange.gov

[4] Nature: Negative Emissions Physically Needed To Keep Global Warming Below 2˚C

These, in addition to novel renewable and energy storage solutions, can be aided by smart investments in advanced research and deserve the committee's continued attention and support.

Third, we should be researching alternatives. In the case of stabilizing temperatures at modest levels or warming, the only alternative to massive reductions in global emissions and deployments of carbon removal would be the deployment of geoengineering technologies that would intentionally offset the warming effect of global emissions. I was honored to testify last Congress before the Subcommittees on Environment and Energy on a research and governance agenda for those technologies. While we had a productive hearing, there is still much that this committee could do to both support early research into these technologies and help establish a set of norms under which that research could be done. We do not know if we will use such technologies, just as we can't be sure that future generations will deploy carbon removal, but we can create knowledge for them.

The General Picture of Climate Science

Note: The text in this section is excerpted from a previously published paper available in full by download,[5] which offers my summary of the state of basic science on climate change and its drivers.

The foundations of climate science date back to the early 19th century, when scientists—using their newfound sophistication in chemistry and physics—became aware that heat trapping gases in the atmosphere maintained global temperatures above freezing. Despite continued scientific study, the field was of little public interest until the 1960s, when scientists became increasingly concerned that greenhouse gas emissions might dangerously interfere with the planet's climate. Such concerns have inspired growing volumes of scientific research into the causes and potential effects of climate change ever since.

The contemporary state of knowledge regarding climate science is compiled by the Intergovernmental Panel on Climate Change (IPCC) and other scientific societies, including the National Academies of Sciences.[6] Just as basic chemistry and physics would predict, industrial activity has indeed increased the amount of greenhouse gases in the atmosphere (primarily CO2), trapped heat, and warmed the climate. Associated changes have been measured in temperatures, rainfall, sea level, and other basic ecological and physical conditions around the world.

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https://www.nature.com/articles/ncomms8958

[5] Climate Science: A Guide to the Debate, Niskanen Center, March 2017: https://niskanencenter.org/wp-content/uploads/2017/03/NISKANEN-CLIMATE-PRIMER-2017-03-13.pdf

[6] National Academies of Sciences and the Royal Society, Climate Change: Evidence and Causes, 2014: https://www.nap.edu/catalog/18730/climate-change-evidence-and-causes

According to the IPCC AR5, these effects should be expected to continue with additional emissions, "increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems."

The 4th National Climate Assessment

The 4th National Climate Assessment presents a detailed evaluation of the available literature on how climate change has affected natural systems and human interests—across different regions, economic sectors, and ecological systems within the United States; how it will continue to do so in the future; and what communities are doing in response. The detailed report released in the fall of 2018 was preceded by a special report on climate science released the previous year.[7]

What, if any, climate change are we seeing in the United States?

The authors of the NCA4 spend a lot of time assessing and identifying how and where weather and climate have changed over the United States in the last century and decades and the relationship. The summary report is itself quite long and detailed, but the topline messages are also pretty clear.

Changes in weather and environmental conditions are evident in the United States, though detecting trends and associating them with global emissions is still an emerging field of study. So while there is pretty high confidence in the connection between global temperatures and emissions, that confidence diminishes as scientists consider more regional and local trends, particular classes of weather events, and individual weather events themselves.

The NCA reports on climate trends in varying phenomena. Some examples from the 3rd chapter on the special report on science show the varying levels of phenomena, and the heterogeneity of regional climate trends. (Bulleted list are quotes)

- Temperature Change: Detectable anthropogenic warming since 1901 has occurred over the western and northern regions of the contiguous United States according to observations and CMIP5 models *(medium confidence)*, although over the southeastern United States there has been no detectable warming trend since 1901.
- Precipitation Change: For the continental United States, there is *high confidence* in the detection of extreme precipitation increases, while there is *low confidence* in attributing the extreme precipitation changes purely to anthropogenic forcing.

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[7] US GCRP, National Climate Assessment 4 Volume 1: Climate Science Special Report: https://science2017.globalchange.gov

- Precipitation Change: For the continental United States, there is *high confidence* in the detection of extreme precipitation increases, while there is *low confidence* in attributing the extreme precipitation changes purely to anthropogenic forcing.
- Extreme Storms: There is broad agreement in the literature that human factors (greenhouse gases and aerosols) have had a measurable impact on the observed oceanic and atmospheric variability in the North Atlantic, and there is *medium confidence* that this has contributed to the observed increase in Atlantic hurricane activity since the 1970s. There is no consensus on the relative magnitude of human and natural influences on past changes in hurricane activity.
- Arctic Changes: It is *very likely* that human activities have contributed to observed arctic surface temperature warming, sea ice loss, glacier mass loss, and Northern Hemisphere snow extent decline (*high confidence*).
- Sea Level Rise: Human-caused climate change has made a substantial contribution to global mean sea level rise since 1900 *(high confidence),* contributing to a rate of rise that is greater than during any preceding century in at least 2,800 years *(medium confidence)*.

The relationship between specific instances of extreme weather and climate change is also complicated, but connections are emerging both in the physical world, and in scientific understanding in the field of extreme event attribution. The NCA lists a few examples where particular temperature events have been linked to climate change with *medium confidence*, like a 2011 heat wave in Texas.

As the NCA reports, such individual assessments are in their early days and confidence in them increases with the detection and attribution of underlying trends (i.e. temperature trends and heat waves) or an understanding of physical mechanisms (i.e. warming surface waters and tropical cyclone strength and wetness).

What are the drivers of climate risks for the United States?

The predicted severity of climate risks depends strongly on the scenarios that you evaluate or highlight. The NCA reports that for a scenario with low future global emissions (RCP2.5), temperature increases over the continental US will range between 2.8 and 7.3 degrees F by the end of the century. But in a scenario with high future global emissions (RCP8.5), temperature increases range between 8.5-11.9 degrees F. In general, the negative effects of climate change get worse with total warming.

In a bit of good news, the worst case scenarios used in NCA4 are looking unlikely. The RCP8.5 scenario combines assumptions of high population growth, stagnating economic growth, and limited energy efficiency and technological innovation, resulting in high levels of long-term ghg emissions. In reality, there have been substantial advancements made in low and zero carbon technologies[8], and GDP per unit of energy use has been rising steadily since 1990[9]. These promising trends, as well as declining levels of global poverty, indicate that the RCP8.5 scenario can likely be avoided.

In a bit of bad news, the best case scenarios used in NCA4 are looking unlikely. The best case scenario (RCP2.6) would require global emissions cuts to proceed rapidly starting very soon. And as I discuss in the next section, nothing in the recent history of emissions indicates that we will come at all close. Even if you add up all that countries pledged to do as part of the Paris Climate Agreement, fully-achieved emissions reductions would still be too slow to meet stringent temperature targets.

In general, it is appropriate for scientific assessment to consider a range of plausible outcomes and even to push the bounds of plausibility to examine how the climate system works in extreme scenarios. And just because something is unlikely does not mean that it is absurd to consider it. Rather, we should consider climate risk across a broad set of scenarios, calibrate our expectations the best we can, and understand that human agency will make a primary difference between the worse case and the best case over this whole century.

Comments on the UN IPCC Special Report on 1.5C

The IPCC Special Report on 1.5C assessed the state of the scientific literature on the relative impacts of global warming between 1.5 and 2 C and the future greenhouse emissions necessary to meet or otherwise exceed those levels of global warming. This report differs from previous efforts from the IPCC, which analyzed scenarios with average warming between 1 and 4 C at the end of this century.[10]

What motivates the 1.5 C goal?
The study was commissioned after diplomats set the ambitious intention of keeping warming to within 1.5C as part of the Paris Climate Agreement, accelerating ambition beyond the previously-established goal of 2C. By its nature, the 1.5C goal was politically determined (same with 2C) and it was motivated by the desire to spare particularly vulnerable people, places, and things from the impacts of imminent climate change.

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[8] International Renewable Energy Energy Agency, Renewable Power Generation Costs in 2017 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf
[9] World Bank: GDP per Unit of Energy Use https://data.worldbank.org/indicator/EG.GDP.PUSE.KO.PP.KD
[10] Intergovernmental Panel on Climate Change, Assessment Report 5: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf

The IPCC survey shows that the impacts of climate change are projected to increase with warming, but that there is no particular global calamity that we know will occur at either 1.5C or 2C, or even beyond 2C with certainty. The world does respond to warming in round numbers, so there isn't some level above which everything is lost or below which everything is fine. Instead, the risks go up with the extent of warming. Halting global warming at 3C would mean less damages than 4, 2C less than 3 C, and 1.5C less than 2C.

As we consider global warming between 1.5 and 2C, the IPCC reports that projections reveal significant and notable effects:

- the increase in global sea level at the end of this century could increase by an additional 4 inches (10 cm) against a rise of 15 (40cm).
- doubling of the land area that will experience a transition between native ecosystems (up to 13% of global land area) and a doubling of the number of animal and insect species that will lose a majority of their historical climatological range.

While even the doubling of a particular effect is significant, it also doesn't demonstrate that there is some qualitative shift in climate impacts that might occur between 1.5 and 2C. But the report does show that particular climate effects could fairly be called devastating for some locations or ecosystems, even at such modest warmings. The prevalence of coral reefs provides an example. At 1.5C, coral reefs are projected to decline by 70-90%. But at 2C, the decline is projected to be greater than 99%—an absolute catastrophe for that particular kind of ecosystem and related economies.

Is 1.5C (or 2C) even possible?

The IPCC authors report that maintaining warming below 1.5C will require emissions reductions that imply a significant demand for technical innovations in low carbon energy. Unfortunately, the emissions reductions necessary to keep temperatures below 1.5C are quite rapid and strain credulity.

The IPCC reports the now common scientific understanding that global temperatures have increased about 1 degree centigrade above pre industrial levels (likely range of 0.8 to 1.2 C). That gives us about the 0.5C of warming before 1.5C. Scientific analysis tells us that there is a relatively proportional relationship between the total historical global emissions and the level of global warming that follows. Temperature increase is a function of the cumulative stock of long lived climate pollutants, primarily CO_2, in the atmosphere. This stock effect means that for every year of emissions, the total amount of warming we expect to see goes up a little bit. It also means that we can roughly translate that remaining warming into remaining global emissions.

For the special report, the IPCC did just that. They found that the so-called carbon budget is between 420 GtCO2 and 770 GtCO2. For reference, current global emissions are about 42 GtCO2 per year and US emissions are just over 5 GtCO2 per year.[11] That means that global warming in excess of 1.5C would be likely within 10 to 20 years at today's global emissions levels. After that, there is enough CO2 in the air to warming beyond the stretch goal of Paris.

To avoid such a warming, global emissions would need to fall precipitously in the coming decades. The IPCC reports 45 percent from 2010 levels by 2030 and by nearly 100 percent by 2050 (since emissions have gone up since 2010, even larger cuts to today's emissions are necessary). The more moderate goal of limiting warming to 2C would similarly require emissions rates to fall 25 percent by 2030 and for emissions to be functionally eliminated by around 2070.

Such a dramatic turnaround is inconsistent with the past few decades, which saw steady increases in CO2 emissions from fossil fuel burning (rising from ~ 25 - 37 GtCO2) and relatively stable emissions from deforestation (between 4 - 6 GtCO2).[12] The rise in fossil emissions is largely attributable to increases in economic growth and energy demand, with a relatively flat CO2 intensity of energy supply globally. That increase was moderated, however, by increasing energy efficiency of the economy.

To continue global economic growth, the energy efficiency of the economy should continue to increase and the CO2 intensity of the energy supply must decrease. That means that we need to reduce the price of energy from clean sources relative to emitting sources, so that the transition to a clean economy is a benefit for society.

While the cost of generating energy from renewable resources like wind and solar has fallen in recent years, and the forward outlook is sunnier still, the reality is that the IPCC report should serve as wakeup call for anyone dedicating their efforts to halting warming at 1.5C, 2C, or more. The rate and depth of emissions cuts implied by these targets indicate that we should endeavor to keep all options on the table when addressing climate change. In a recent survey of the available literature of decarbonizing just the U.S. power sector, authors Thernstrom and Jenkins surveyed 30 papers and found a sturdy consensus that "a diversified mix of low-CO2 generation resources offers the best chance of affordably achieving deep decarbonization.[13]" In particular, the ability

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[11] US Environmental Protection Agency, 2018 Emissions Inventory: https://www.epa.gov/sites/production/files/2018-04/documents/9509_fastfacts_20180410v2_508.pdf
[12] Global Carbon Project, 2018 Global Carbon Budget: http://www.globalcarbonproject.org/carbonbudget/18/files/GCP_CarbonBudget_2018.pdf
[13] Jenkins and Thernstrom, DEEP DECARBONIZATION OF THE ELECTRIC POWER SECTOR INSIGHTS FROM RECENT LITERATURE, 2017 :

to generate and dispatch electricity from non-renewable sources such as energy storage, nuclear reactors, or fossil-fuels with carbon capture and storage appears to be of great value.

After emissions reach zero, the scenarios examined by the IPCC that limit warming to 1.5C require substantial negative emissions, or carbon dioxide removal. That is the removal of CO2 from the atmosphere through technological processes (like burning cultivated biomass for energy and capturing the resulting CO2 before it escapes to the atmosphere) or growing trees in forests. Carbon dioxide removal is invoked in all scenarios that appear consistent with limiting warming to 1.5C in this century in the IPCC report. The amount of carbon dioxide removal invoked across the different scenarios analyzed by the IPCC is primarily driven by how much is emitted in the next few decades, with slower emissions reductions implying higher burdens for carbon removal. The amount of carbon dioxide that would need to be removed from the atmosphere is gargantuan, between 100-1000 GtCO2, over the course of the century.

Supporting early development of the technologies and processes that will be necessary to remove CO2 at those levels would be a helpful contribution from this committee. The prospective scope of such an operation is enormous and is a real opportunity for industrial innovation. Given the advantages of fossil fuels, it is reasonable to think that they will continue to be a major energy source, creating a market for carbon capture as part of the emissions reductions portfolio. And the industry opportunity is large. A study published last week estimated that a meaningful deployment of carbon capture would be approximate 2-4 times the modern day oil industry, by volume of product.[14] If you add in the potential for a carbon removal industry, then the scale of the opportunity grows.

Climate action is not inconsistent with the continued use of fossil fuels in coming decades. In fact, successfully meeting these proposed targets will probably require their continued use in conjunction with carbon capture.

Conclusion and Recommendations

Thank you for your time today. Climate change is an important topic for public policymakers to which scientific information can make significant inputs. We all know that scientific considerations are not the only factor at play, but it is and remains one of our greatest achievements. In this case, science can help us understand the scope of the problem and the effectiveness of proposed responses. The U.S. research enterprise overseen by this committee is

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https://www.innovationreform.org/wp-content/uploads/2018/02/EIRP-Deep-Decarb-Lit-Review-Jenkins-Thernstrom-March-2017.pdf

[14] https://www.nature.com/articles/nclimate3231

a valuable resource in either regard. I thank the Committee for its attention to this issue and look forward to an ongoing conversation.

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Joseph Majkut is director of climate policy at the Niskanen Center. He is an expert in climate science, climate policy, and risk and uncertainty analysis for decision making. He is frequently cited by prominent media outlets; his writing has been featured in scientific journals, public media, and environmental trade press; and he has been invited to testify before Congress on climate and scientific research. Before joining the Niskanen Center, he worked on climate change policy in Congress as a congressional science fellow, supported by the American Association for the Advancement of Science. He holds a PhD from Princeton University in Atmospheric and Oceanic Sciences, a master's degree in Applied Mathematics from the Delft University of Technology, and a bachelor's degree in Mathematics from Harvey Mudd College.