Testimony of Dr. Philip B. Duffy
U.S. House of Representatives Committee on Science, Space, and Technology
Hearing on "Using Technology to Address Climate Change"
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Thank you Mr. Chairman, ranking member Johnson, and members of the committee for the opportunity to appear today.

I am Philip Duffy, President and Executive Director of the Woods Hole Research Center. I have a doctoral degree in applied physics from Stanford, and began my career in the nuclear weapons complex at Lawrence Livermore National Laboratory. There I worked in the group that tested nuclear weapons at the Nevada Test Site, and also on strategic defenses against ballistic missile attack.

The bulk of my career, however, has been devoted to a different and equally important threat, global climate change. For more than 20 years I studied climate change as a research scientist; I spent 3 years at a climate change communications organization, Climate Central (ending as their Chief Scientist); and between 2011 and 2015 worked on designing and implementing climate policies in the Obama White House.

Consensus on global warming and its human causation

Today I will discuss the need for technologies for mitigating (preventing) unacceptable climate change, for adapting to changes we can't prevent, and for monitoring greenhouse gas emissions. A top-line message is that development and deployment of these technologies present an important opportunity for US researchers and businesses. I will also mention the positive economic benefits that can be obtained from well-designed climate policies.

I'll start, however, by reviewing some of what we know about climate change and its human causation.

The fact of global warming is beyond question. An enormous quantity of observational evidence clearly demonstrates warming of the atmosphere and ocean, melting of land and sea ice, sea level rise, reductions in snow cover, and a host of other consequences of warming, such as increases in extreme precipitation and other forms of extreme weather.

The scientific consensus on human causation of observed warming is as strong as on the fact of warming itself. The latest scientific estimate presented by the Intergovernmental Panel on Climate Change (IPCC) is that humans are responsible for essentially all of the warming observed over the past 60 or so years. This is supported by the latest US National Climate Assessment, the first volume of which was released by the Trump administration in November 2017. This Assessment found that "…based on extensive evidence, … it is extremely likely that **human activities, especially emissions of greenhouse gases, are the dominant cause of the observed warming since the mid-20th century**. For the warming over the last century, there is no convincing alternative explanation supported by the extent of the observational evidence."

It is important to note that world governments also share the consensus on human causation of climate change. IPCC summary statements, including those on attribution of warming to human activities, are not only produced and reviewed by hundreds of scientists from nations around the world, they are approved by governments as well. In fact, every sentence in the IPCC summary documents, again including those on human causation of climate change[1], were approved *unanimously* by national representatives. Furthermore, every country in the world has signed onto the Paris climate agreement, which commits them to taking steps to reduce their contributions to climate change. There would be no reason to do that if they did not recognize both the importance of the climate threat and the human role in causing it.

Let me add that any alternative explanation for recent climate change (other than human greenhouse gas emissions) faces two challenges: first, it must provide an alternative physical mechanism for observed warming, and second, it must explain why the observed increase in atmospheric greenhouse gases is *not* responsible for observed warming. This would require overturning the scientific understanding of the greenhouse effect, that has been developed over the course of nearly two centuries and that, in its current form, explains observational data with striking fidelity.

Finally on this subject, while we understand more than enough about climate science to know that we need to urgently implement strong climate policies, there are important policy-relevant issues that need to be better understood. Chief among these may be "tipping points," climate processes which would be impossible to stop after they have been set in motion, and which would have severe societal consequences. These are discussed further below. I encourage this Congress to support increased funding for research into these questions and others that the Congress may feel need to be better understood. In particular, if despite the overwhelming evidence supporting human causation of climate change, the Congress feels that the human role in climate change needs to be better understood and debated, then I encourage them to support increased research funding, in order to ensure that that debate is as well-informed as possible.

Tipping points and the urgency of addressing climate change

The oft-cited urgency of addressing climate change has a strong basis in science. Part of this basis is the long lifetime of CO2 in the atmosphere. This implies that even if human greenhouse gas emissions were to instantly and completely cease, the elevated global temperature and its many climatic and human consequences would not materially improve for centuries. Sea level would continue to rise for a thousand years. The policy ramifications of this are fundamental: "wait and see" is a bad climate policy, because if the effects of climate change become intolerable it will be too late to avoid being forced to cope with them for centuries, if not longer.

The urgency of addressing climate change is also driven by thresholds and tipping points such as the onset of large-scale emissions of greenhouse gases from thawing permafrost. The disintegration of major land ice sheets is another process which may become irreversible and which would produce devastating global consequences—massive sea level rise. Improved scientific understanding of these processes, and observations showing them starting to occur, are the main reasons why policy discussion increasingly focus on the stricter goal of limiting global

[1] The most recent such statement is: "It is *extremely likely* that human influence has been the

warming to 1.5ºC rather than the older 2º goal. As noted above, we urgently need more research in order to understand as precisely as possible where these tipping points lie, to allow us to refine our top-line climate policy goals (e.g. should we limit warming to 1.5º, 2º, or something else?) in order to be sure to avoid the consequences of crossing these thresholds and tipping points.

The urgency of addressing climate change is also driven by societal factors. For example, well before coastal areas are permanently or even usually inundated, property values in these areas may drop. Inability to get affordable insurance, or any insurance at all, may accelerate this decline. We urgently need policies to delay or prevent inundation and flooding, as well scientifically and economically sound policies on insurance, disaster response, rebuilding, and so on.

The need for technologies

Technology will play an essential role in minimizing the effects of climate change and adapting to the effects we cannot prevent, as well as in measuring greenhouse gas emissions. I would like to see our government help US businesses to develop these technologies and sell them to the rest of the world. If we don't, someone else will, and I would hate for our country to lose that opportunity.

To begin with reducing emissions, both developed and developing countries want, deserve and will seek the best possible quality of life for their people. This means an increase in global energy use. It is very much in our own self-interest to help other countries to accomplish this with technologies that do not contribute to climate change. Otherwise, the greenhouse gas emissions from these countries will result in climate consequences that will be extremely harmful to all nations, including us. Key technologies needed for mitigation include those for carbon-free energy generation, storage, and transmission, as well as for climate-friendly agriculture and forest management. In addition, we need technologies for energy efficiency, for electrification of the transportation and industrial sectors, and so on. Finally, I believe that we should at least investigate technologies for counteracting the effects of atmospheric greenhouses gases, a practice known as geoengineering.

Because we have delayed so long at implementing effective emissions reductions measures, we also need technologies to remove CO2 from the atmosphere. Although it may in the future be possible to achieve this using technological means, it is possible now to achieve significant CO2 removal using land management practices like reforestation and climate-smart agriculture. I recommend adoption of these practices as they have significant positive side-benefits, including making us more resilient to climate threats.

An enormous range of technologies is needed for climate adaptation. These include technologies to cope with extreme weather, water contamination, vector borne diseases, to increase resilience of crops, and so on. With respect to extreme weather, assessments have shown that we are under-prepared even for the present climate, meaning that investments in preparedness and resilience would produce net economic savings even absent human-caused climate change. Upgrading our physical infrastructure could be an important step in increasing resilience, if that infrastructure is designed with the climate of the 21st century in mind.

New technologies are also needed to measure greenhouse gas emissions. Any policy to meaningfully control climate change will require the ability to accurately and verifiably measure these

emissions. Needed technologies include those for measuring carbon in the atmosphere, ocean, forest, soils, etc. both remotely and *in situ*, as well as advanced modeling to understand where emissions are coming from. Here again, I would hope that our government would help the United States to be the leader in the development and deployment of such technologies. The recent decision to cancel NASA's Carbon Monitoring System is ill-advised as the information gathered by such systems will generate real value at low cost.

Climate policies and their economic consequences

Mitigation and adaptation are sometimes presented as alternatives, but this is a false dichotomy. Focusing exclusively on mitigation would leave us needlessly vulnerable to harms from unavoided climate change. Ignoring mitigation would expose us to potentially catastrophic consequences. We are already practicing both mitigation and adaptation, and this will continue to be true. As noted above, investments in adaptation often save more money than they cost.

Results of early studies suggest that the same is true of mitigation policies. We are beginning to have enough real-world experience with these policies that we can learn valuable lessons by studying not only their effectiveness at reducing greenhouse gas emissions but also their immediate economic impacts. Forty countries and 20 subnational jurisdictions are now under a carbon pricing policy (carbon tax or emissions trading system). Assessments of these policies have found that well designed climate policies can not only reduce greenhouse gas emissions but have immediate positive economic impacts. Several recent studies, for example, found that the Regional Greenhouse Gas Initiative (RGGI), a "cap and trade system" on greenhouse gas emissions from the electric power sector in nine northeastern states, has resulted in billions of dollars of net economic benefit to the region[2], as well as $5.7B in savings due to improved health outcomes[3]. While these studies are limited in scope, the idea that the same policies that address climate change can also improve the economy is powerful and important.

Conclusion

The threat of global climate change is real and urgent, and is recognized as such by scientists and governments around the world. Advanced technologies of many types will be essential in minimizing and adapting to this threat.

I recommend specifically:

• Accelerated deployment of carbon-free energy production technologies we have now, especially wind and solar;

• Development of new such technologies, as well as technologies for energy storage and transmission;

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[2] https://www.dec.ny.gov/docs/administration_pdf/ag11rggi.pdf

www.analysisgroup.com/uploadedfiles/.../analysis_group_rggi_report_july_2015.pdf

www.analysisgroup.com/uploadedfiles/.../analysis_group_rggi_report_april_2018.pdf

[3] http://abtassociates.com/RGGI

- Development of technologies to remove CO2 from the atmosphere;

- Research into geoengineering;

- Adoption of land-management practices that remove CO2 from the atmosphere;

- Development of improved technologies for measuring GHG emissions and global carbon stocks

- Accelerated research into understanding climate thresholds and tipping points, in order to inform top-line climate police goals (e.g. 2° vs 1.5°);

No nation is better position than ours to develop these technologies and to profit economically from their deployment. I enthusiastically encourage this Congress to support and enable US leadership in this area.

Philip B. Duffy is President and Executive Director of the Woods Hole Research Center (WHRC). Dr. Duffy was trained in physics and started his career in the nuclear weapons complex at Lawrence Livermore National Laboratory. There he was involved with testing nuclear weapons at the Nevada Test Site, and also worked on strategic defenses against nuclear ballistic missile attack. Turning to the threat of global climate change, Dr. Duffy studied the problem for 20 years as a research scientist. Between 2011 and 2015 he helped to formulate and implement domestic and international climate policy in the Obama White House. Prior to joining the White House he was Chief Scientist at Climate Central, a non-profit dedicated to increasing public understanding and awareness of climate change. He has been a Senior Scientist at Lawrence Livermore National Laboratory, an adjunct faculty member at UC Merced, and has held visiting academic posts at Stanford University and at the Carnegie Institution for Science. Dr. Duffy has over 75 peer reviewed publications, has served on committees of the National Academy of Sciences, and as an advisor to the US Department of State. He has a bachelor's degree from Harvard and a PhD from Stanford University.