Data or Dogma? Promoting Open Inquiry in the Debate over the Magnitude of Human Impact on Earth's Climate

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Thank you Chairman Cruz, Ranking Member Peters, distinguished members of the U.S. Senate Committee on Commerce, Science, and Transportation for the opportunity to come before you today and discuss this very important topic.

I am David Titley and currently serve as the Founding Director of the Center for Solutions to Weather and Climate Risk at the Pennsylvania State University. I had the honor of serving in the United States Navy for 32 years and retired last year as a Rear Admiral and Assistant Deputy Chief of Naval Operations for Information Dominance. When I retired, I was also the Oceanographer and Navigator of the Navy, and Director of U.S. Navy Task Force Climate Change. Subsequent to my time in the Navy, I served as the Chief Operating Officer position of the National Oceanic and Atmospheric Administration (NOAA). My Center at Penn State currently receives no Federal Funding. Although I have consulted with many distinguished climate scientists in preparation for this testimony, my views are my own -- any mistakes are my responsibility.

I am here today because I believe coming to a consensus on how to develop policies that address the challenge of a changing climate is a very important discussion for our nation's leadership to have. Thank you for holding this hearing.

In the Navy we have a saying, to just give me the 'Bottom Line Up Front' or BLUF. So here's my BLUF for today's hearing:

- **We know how to do Science:** Science is not a simple linear process, performed in an isolated, sterile environment, but rather an iterative process with continual interaction between exploration and discovery, feedback and input from peers, inputs from society, but most importantly, testing ideas, called hypotheses and theories, with evidence. New evidence can change existing ideas. The better ideas fit actual observations, disparate or seemingly unrelated observations or previously unknown observations, the more likely the idea is to be accepted widely by science. Results are provided in many venues, but peer-reviewed journals are especially important. Peer-review does not guarantee the ideas being published are correct, but the process does ensure the work acknowledges previous work in that field, the experiments and methods were well-designed, the evidence cited logically leads to the conclusion. If new evidence becomes available, or subsequent researchers find errors in the methods published, the original ideas are modified. Science is based on the cumulative weight of the evidence available. If initially published contrarian results stand the test of independent confirmation and corroboration, these initially contrarian (or even revolutionary) results become part of the accepted body of science.

- **The climate is changing more rapidly than has been observed in the past; we understand why that is so, and we understand that those changes will continue, absent meaningful action in reducing Greenhouse Gas emissions:** The change in the climate, and therefore the change in the weather, is real. Multiple independent sources of data show a rise in temperatures and rise in the ratio of record high temperatures to record low temperatures; an increase in the intensity of precipitation events – that is, the hardest rains are getting harder; the continued collapse in the area and amount of summer-time sea ice in the Arctic Ocean; an acceleration of sea level rise; acidifying oceans; and ecosystems moving poleward and up in elevation where possible. We understand why the climate is changing, based on science extending back to the mid-19th century. The basic concept of greenhouse gasses trapping heat and keeping the atmosphere warmer than it would be in the absence of these gasses is extremely well understood. This idea explains not only the temperature of the Earth, but the same concept also applies to understanding the temperatures of Venus and Mars.[1]

- **We know how to succeed even when the future is not perfectly known:** Traditional risk planning takes the chance or probability of an event and multiplies it by the impact. But even when it is difficult to assess the likelihood of a specific event, there are still available methods by which risk planning and mitigation can be accomplished. Our national security teams frequently have to account for these "deep uncertainties" and they have a variety of tools to assist them. Rich scenario planning, assumptions-based

[1] MacCracken, M. "Climate Change in Six Well-Documented Findings". http://www.climate.org/topics/climate-change/science-in-six-findings.html

planning and similar methods can be used with the goal of identifying all plausible vulnerabilities and their subsequent impacts. National Security and strategic military planners have used these tools successfully for decades – we can apply these methods and adapt them to the climate change challenge.

The earth's climate has naturally varied for millions of years (Figure 1 – From John Englander "High Tide on Main Street"; it will continue to do so for millions more (e.g., . However, humans, primarily through the release of greenhouse gases, also have the capability to modify the earth's climate in a way that previously could occur only by nature. If the climate has always changed in the past and will do so in the future, then why do we care? We care because we are forcing a change to a system that has been remarkably stable in the past 8-12 thousand years (Figure 2 -- From John Englander "High Tide on Main Street"); the time when humans developed agriculture, civilization and our modern way of life. It's not that the climate of the past few thousand years is optimal *per se*, but its stability allowed us to base a civilization on an overall predictability of where our coasts would be, when the rains would come, and the length of the growing seasons. Later on we would construct our buildings, towns, and cities all based on a historical understanding of the averages and extremes of our historical climate. And most importantly, we made a fundamental assumption that the future climate would be like the past. That assumption no longer holds.

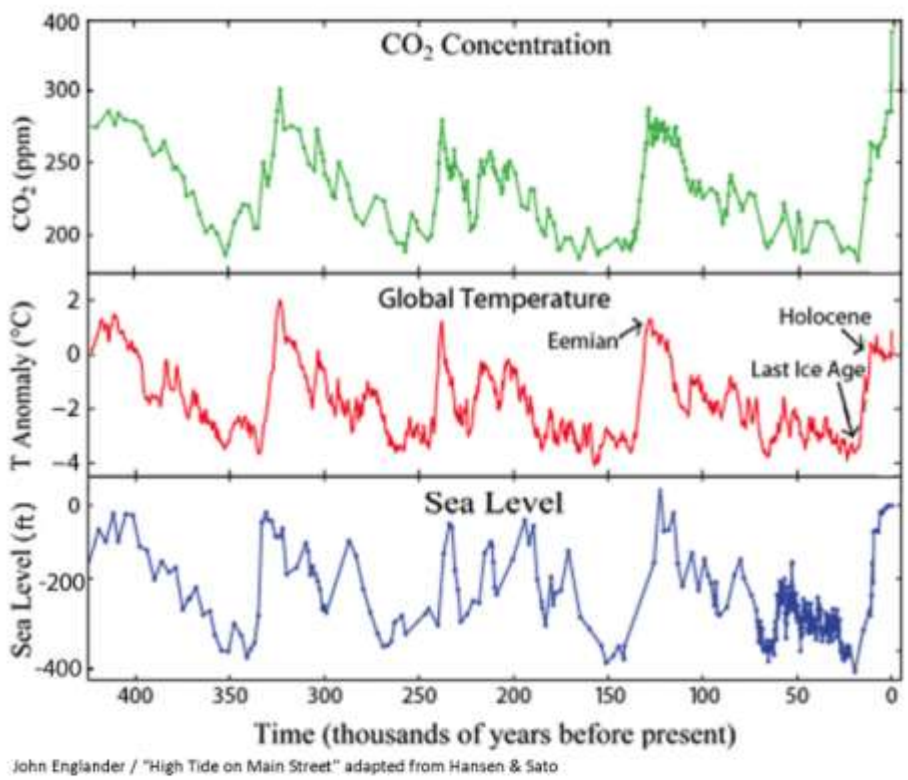

Figure 1 – From John Englander "High Tide on Main Street"

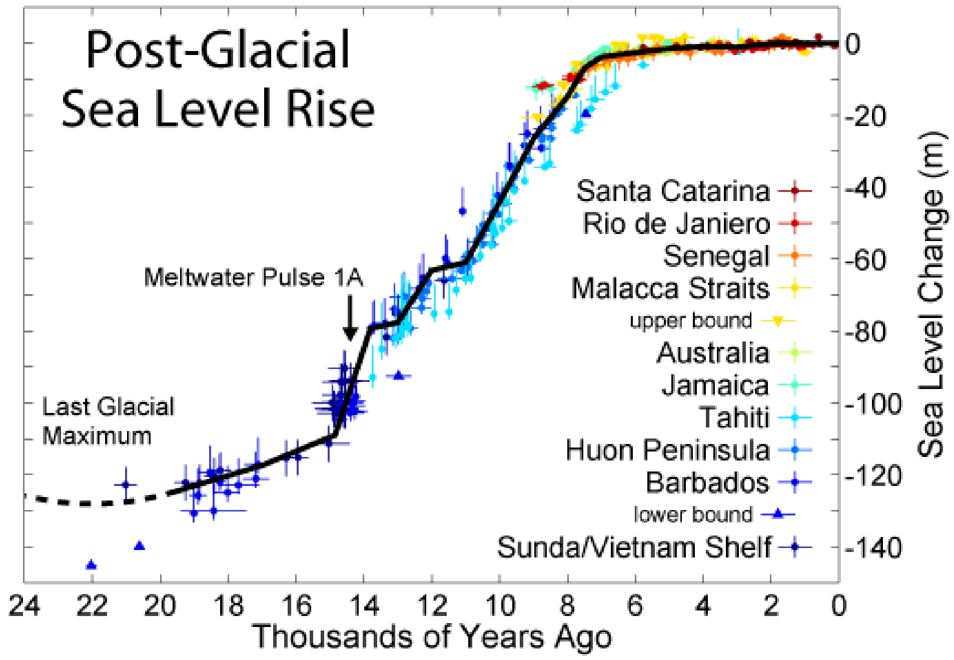

Figure 2 -- From John Englander "High Tide on Main Street"

Dr. John Holdren, Director of the White House Office of Science and Technology Policy, provided extensive written testimony on the subject of climate change data and evidence to the U.S. House of Representatives Committee on Science, Space and Technology in September 2014. While I have no ties to the current administration I believe Dr. Holdren describes accurately the state of climate science today. The following is an extract of his written statement:

"There is an immense amount of [climate science] primary, peer-reviewed, published research …carried out by a wide variety of competent national and international bodies (including Federal agencies and scientific advisory boards and committees reporting to them). Important examples include the comprehensive reviews by the U.S. National Academies[2] and the Intergovernmental Panel on Climate Change (IPCC)[3], the recent joint review by the U.S. National Academy of Sciences and the U.K.'s Royal Society of London[4], the Second and Third U.S. National Climate Assessments[5], the annual State of the Climate reports of the U.S. National

[2] The National Academies reports on climate change include the four-volume set, *America's Climate Choices* (2010)
and a host of other reports completed since 2010, all accessible at: http://nas-sites.org/americasclimatechoices/.

[3] Intergovernmental Panel on Climate Change (IPCC) 2007 and 2013-2014 IPCC Fourth and Fifth Assessments, accessible at: http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1

[4] Climate Change: Evidence and Causes – An Overview from the Royal Society and the U.S. National Academy of Sciences, 2014: http://dels.nas.edu/resources/static-assets/exec-office-other/climate-change-full.pdf

[5] *Global Climate Change Impacts in the United States*, 2009: http://nca2009.globalchange.gov and *Climate Change*
Impacts in the United States, 2014: http://nca2014.globalchange.gov.

Oceanic and Atmospheric Administration[6], the periodic synthesis and assessment reports of the U.S. Global Change Research Program[7], and the first Quadrennial Energy Technology Review of the U.S. Department of Energy[8]. Notably, the U.S. National Climate Assessments, which are required under the Global Change Research Act of 1990, reflect substantial input from the public, outside experts and stakeholders. The most recent such Assessment, which was released in May of 2014, was the result of a three-year analytical effort by a team of over 300 climate scientists and experts, informed by inputs gathered through more than 70 technical workshops and stakeholder listening sessions held across the country. The resulting product was subjected to extensive review by the public and by scientific experts inside and outside of government.

The Natural Science of Anthropogenic Climate Change

Decades of observation, monitoring, and analysis have demonstrated beyond reasonable doubt that:

(1) the Earth's climate is changing at an unusual pace compared to natural changes in climate experienced in the past;
(2) emissions of carbon dioxide and other greenhouse gases from human activities, principally the combustion of fossil fuels but also land-use change, are the principal drivers of the recent and ongoing changes in climate;
(3) climate change is already causing harm in many parts of the world (and many parts of the United States);
(4) this harm will continue to grow for some time to come, because of the time lags and inertia built into the Earth's climate system and the inertia in civilization's energy system (which prevents drastically reducing the offending emissions overnight); but
(5) there is a large difference between the amount of additional harm projected to occur in the absence of vigorous remedial action versus that expected if such action is taken promptly.

The recent measured changes in climate include a multi-decade increase in the year-round, global-average air temperature near Earth's surface, but they are not limited to that. The changes also include increased temperatures in the ocean; increased moisture in the atmosphere; increased numbers of extremely hot days; changed patterns of rainfall and snowfall; and, in some regions, increases in droughts, wildfires, and unusually powerful storms.

In consequence of the temperature increase, moreover, glaciers are melting, the Greenland and Antarctic ice sheets are losing mass, and sea level is rising. While the pace of sea-level rise is relatively slow—the current rate would produce an increase of about a foot over a century—there are three main reasons that the problem should not be underestimated:

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6 National Oceanic and Atmospheric Administration (NOAA) State of the Climate reports, accessible at: http://www.ncdc.noaa.gov/sotc/

7 http://www.globalchange.gov/browse/reports

8 Department of Energy (DOE) 2011 Quadrennial Technology Review: http://energy.gov/sites/prod/files/QTR_report.pdf

(1) The rate appears to be increasing and is now about twice the average for the 20th century; increases as high as 1 to 2 meters (3.3 to 6.6 feet) above the pre-industrial value by 2100 cannot be ruled out.[9]
(2) Even modest amounts of sea-level increase constitute a significant threat to ecosystems and infrastructure in low-lying coastal areas, not least because of the amplification of storm surges and increased intrusion of salt water into coastal aquifers.
(3) The momentum in the processes driving sea-level rise is such that it is expected to continue for centuries even under the most optimistic scenarios for climate-change mitigation; it can be slowed, but it cannot be stopped on any time scale of practical interest.

The "fingerprint" of human responsibility for most of the climate change observed over the past few decades is unmistakable: science has established persuasively that the atmospheric build-up of the key greenhouse gases has resulted from human activities; and the spatial and temporal patterns as well as the magnitudes of the observed changes in temperature are consistent with what theory and models predict would result from that build-up, after allowance is made for the partially offsetting effect of increased atmospheric concentrations of reflective and cloud- forming particulate matter (also of human origin).

Civilization's emissions of carbon dioxide, in particular, have led not only to a build-up of the stock of this important heat-trapping gas in the atmosphere (where it's responsible for close to half of the total warming influence of all the heat-trapping substances humans have added over time); those emissions have also led to an increase in the dissolution of carbon dioxide into the surface layer of the ocean. There the dissolved CO_2 forms carbonic acid (H_2CO_3) and thus lowers the pH (increases the acidity) of ocean waters. This ongoing acidification increasingly puts at risk coral reefs and other marine organisms that build their shells or skeletons from calcium carbonate (including clams, oysters, and some plankton).

The foregoing conclusions are based on an immense number of observations and measurements made by thousands of scientists at both governmental and nongovernmental institutions around the world, as well as on fundamental understandings about atmospheric physics and increasingly sophisticated computer models of ocean-atmosphere-ecosystem interactions, all recorded in tens of thousands of peer-reviewed scientific publications. These key findings about climate change have been endorsed by every major national academy of sciences in the world, including those of [the United Kingdom], China, India, Russia, and Brazil as well as that of the United States, and by nearly every U.S. scientific professional society, by the World Meteorological Organization and the UN's Inter- governmental Panel on Climate Change (IPCC), and by the recently released Third U.S. National Climate Assessment."

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[9] Note: The highest value cited by the IPCC's 2013 climate-science synthesis is 1.25 meters, but a December 2012 NOAA report put the upper limit at 2 meters (see Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. 2012. *Global Sea Level Rise Scenarios for the US National Climate Assessment*. NOAA Tech Memo OAR CPO-1: http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf)

(I have attached additional, more technical parts of Dr. Holdren's statement providing evidence of changes in our climate in Attachment A, submitted with this testimony.)

I would be remiss if I did not address the so-called 'pause' in global surface temperatures. Dr. Holdren provides additional details (submitted as part of Attachment A). It is easy to find arbitrary 5-15 year periods when, with careful choosing of the start and stop dates, one can claim there has been no change in global temperatures. This method of analysis though does not account for the longer-term upward trend that persists through the relatively short-term variations. As an analog, I drive west on Interstate 70 from Washington DC back to Penn State. However, for nearly the first 25 miles in Pennsylvania, I-70 runs north, or even northeast. But even with that short-term variation (to account for the mountains) the road, overall, still takes me from east to west. Likewise, due to natural variability, there are short-term ups and downs in year-to-year temperature. But this structure does not remove the long-term, and upward, trend. A recent graphic (Figure 3) from Dr. Kevin Trenberth of the National Center for Atmospheric Research[10] shows this trend, and also shows how 2015 is very likely to be the warmest year recorded in the modern record – and by a significant margin.

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[10] http://www.huffingtonpost.com/dr-kevin-e-trenberth/fact-not-opinion-climate-_b_8703012.html

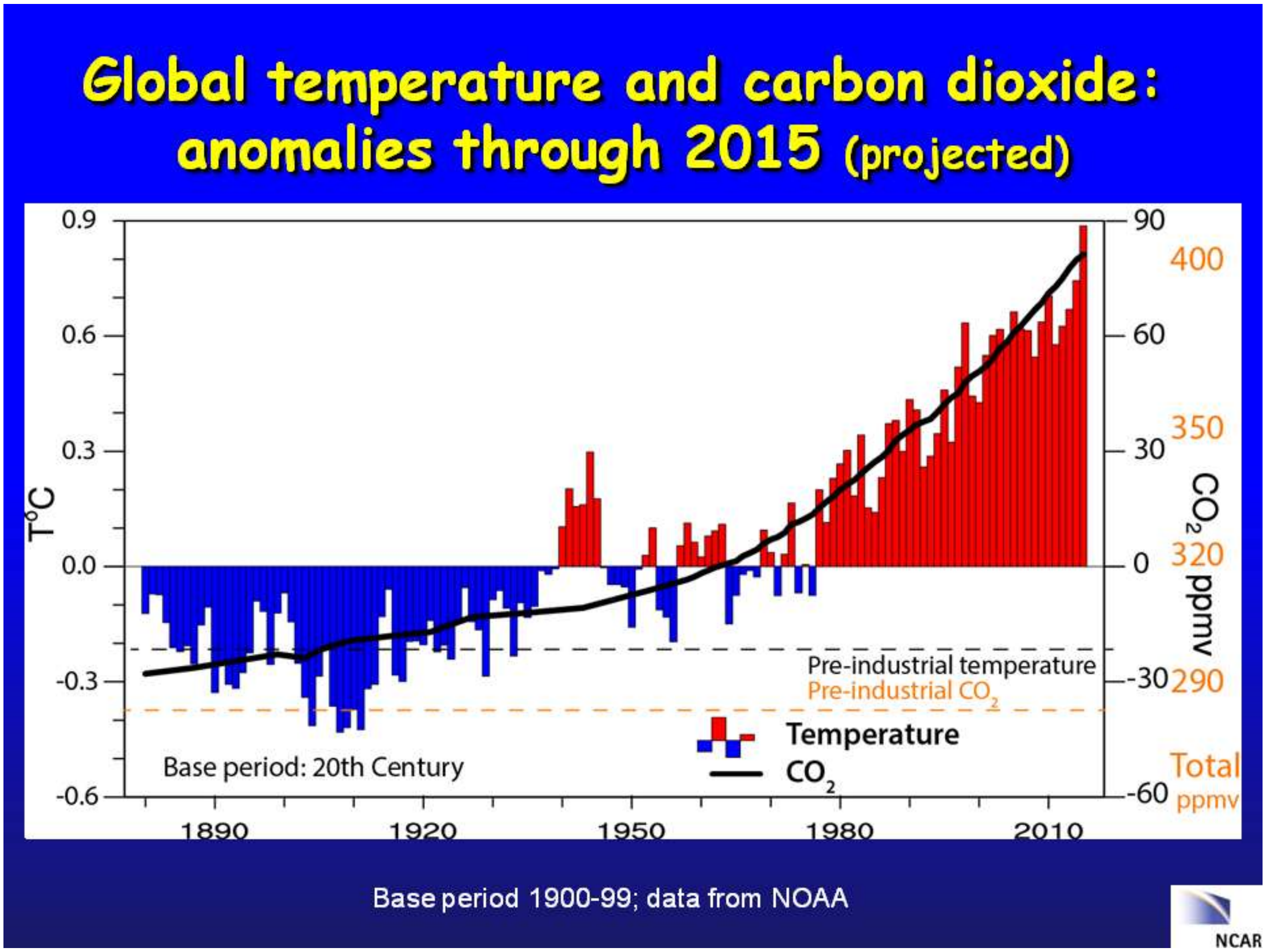

Figure 3 Global Temperature change and CO2 concentration

In summary, a combination of multiple, independent sources of data provide the basis to the latest conclusion from the Intergovernmental Panel on Climate Change: "Warming of the climate system is unequivocal, and since the 1950's, many of the observed changes are unprecedented over decades to millennia… Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system[11]." We should not be surprised; these conclusions rest on science discovered in the 19th century by Fourier, Tyndall, Arrhenius and their colleagues[12] and validated by many scientists in the subsequent decades.

It is worth noting that private industry independently arrived at these same conclusions decades ago. Recently released documents[13] show that in 1980 Exxon researchers projected the impacts

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[11] Summary for Policy Makers of the Working Group I contribution to the IPCC Fifth Assessment Report (2013)

[12] http://www.aip.org/history/climate/co2.htm

[13] http://insideclimatenews.org/news/01122015/documents-exxons-early-co2-position-senior-executives-engage-and-warming-forecast

on global temperature due to increasing greenhouse gasses with astonishing accuracy (e.g., Figure 4). Again, the basis of the science of climate change is exceptionally well-understood and can be – and has been – applied by many researchers inside and outside the government.

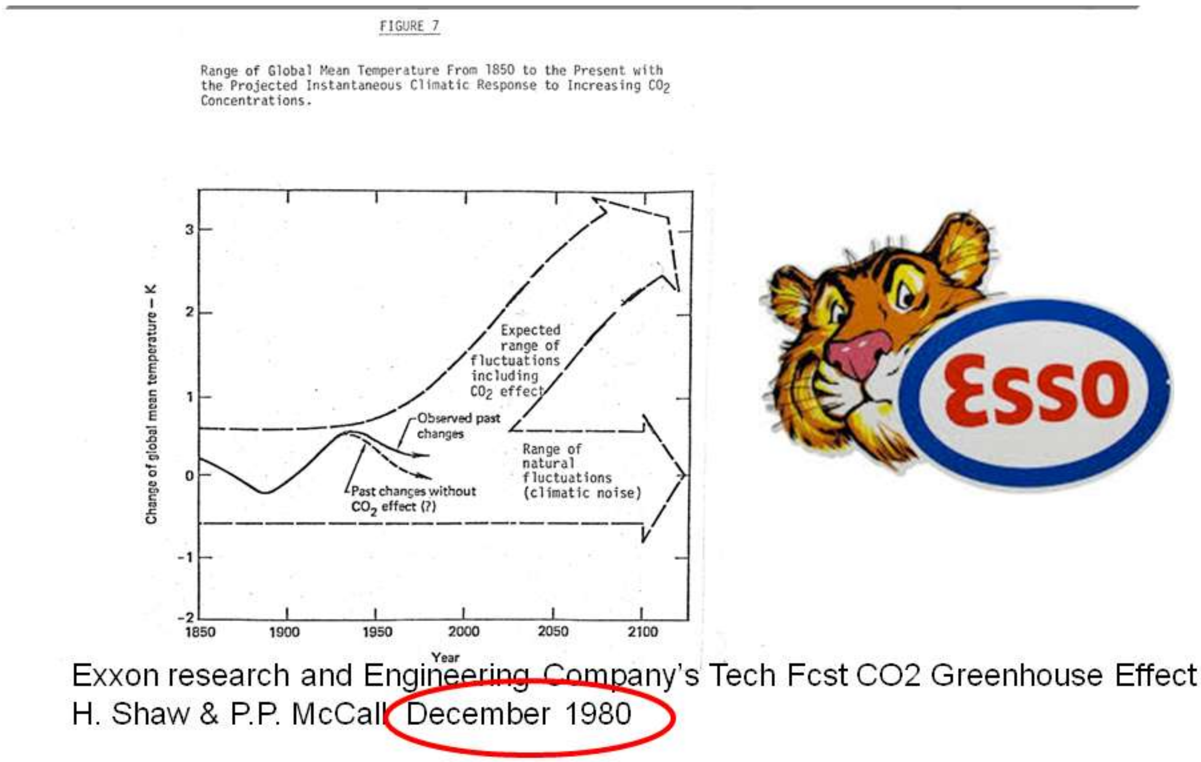

Figure 4 Exxon Projection of global temperatures

So what should we do? I recommend we take a risk-management approach, similar to how the CNA Military Advisory Board (MAB) has done in their most recent report on the risks of climate change to security.[14] Although most of the CNA MAB members are not scientists, their positions as former senior three- and four-star leaders in the United States Military trained them to seek and assess technical advice from many different fields of expertise. They have accepted the overwhelming evidence of the mainstream, international science community, and understand that if significant new and compelling evidence is discovered, the conclusions may need to be adjusted accordingly. Climate risks and security risks share another trait in common: "The worst matters much more than the bad"[15]. In other words: What are the near-term and future

[14] "National Security and the Accelerating Risks of Climate Change.", CNA Corporation, May 2014. https://www.cna.org/cna_files/pdf/MAB_5-8-14.pdf

[15] Burroughs, William "Climate Change in Prehistory: The End of the Reign of Chaos", Cambridge University Press, 2005

risks to our way of life – and what policies and structures should we put in place to manage and mitigate those risks?

How might we meet this challenge? One way might be to start with these four recommendations, consistent in broad goals with the President's Climate Action Plan[16]:

- Set up and support a monitoring system that will allow the U.S. and the world to detect and assess changes to future climate. Assign specific responsibilities. Many National Academies of Science (NAS) reports have called for such a monitoring system. As a recent example, the NAS 'Abrupt Climate Changes' report calls for such a monitoring system.
- Adjust policies today for what we know – and for what we might reasonably expect in the coming decades. Ensure we do not simply plan for the best case or even the most likely, but also consider seriously the most damaging and harmful scenarios (think 'Katrina' and 'Sandy'). We learned in the military a long time ago that hope by itself is rarely a good strategy.
- Invest in better understanding – and ultimately prediction – at the boundary between weather and climate. While scientifically this is very challenging, it is also very important for people and a myriad of decisions. From a security, economic, agricultural, infrastructure and policy perspective, greater climate knowledge of the next few seasons to the next decade or two would be extremely useful. While we should not use today's uncertainty as an excuse to defer action, better understanding of the climate over the next 2-20 years would be very useful in allocating scarce resources. The Department of the Navy is funding today the 'Earth System Prediction Capability' or ESPC – an interagency program designed to provide our country the next-generation of integrated air-ocean-ice-land prediction system[17]. Navy is working with other components of the DoD, as well as NOAA, NASA and the Department of Energy to ensure our nation has the world's best operational weather and climate prediction tools at our disposal. This national imperative must be a national priority.
- As we work on adapting to our changing climate we should not lose sight of the big picture: how to move the world's energy system to a predominantly non-carbon based energy source to power the world. How can we unleash the innovation and energy that makes our country great to solve one of the grand challenges of the 21st Century? The United States has responded to grand challenges of the past, in part by investing for the future. As seen in Figure 5, we responded to President Kennedy's call to go to the moon and President Nixon's response to the 1973 Arab Oil Embargo. To date though, there has been no serious response to the need to transforming our energy system. We are the

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[16] http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf

[17] http://espc.oar.noaa.gov/

country that is developing a self-driving car and whose private companies can send satellites to geosynchronous orbit. With the right policies and encouragement from the Federal Government I am sure our private sector can develop – and profit from – energy solutions that will power the world in a sustainable fashion into the future.

In closing, our country is dealing with a significant change in the world's climate; it is a very serious challenge and if we do not manage this risk climate change, unchecked, will make many of our existing threats worse. But our country has met challenges of this magnitude before and succeeded – and we will do so again. While we don't know everything – and we never will – we do know more than enough to act now. By focusing our efforts in a risk-based framework on meeting the climate challenge, we can prepare for the short-term while shaping our longer-term future. We can provide the policies, stability and guidance our country needs to unleash our country's energy, creativity and initiative. I am convinced we will be proud and amazed at what we can accomplish.

Thank you very much for your time and attention; I look forward to taking your questions.

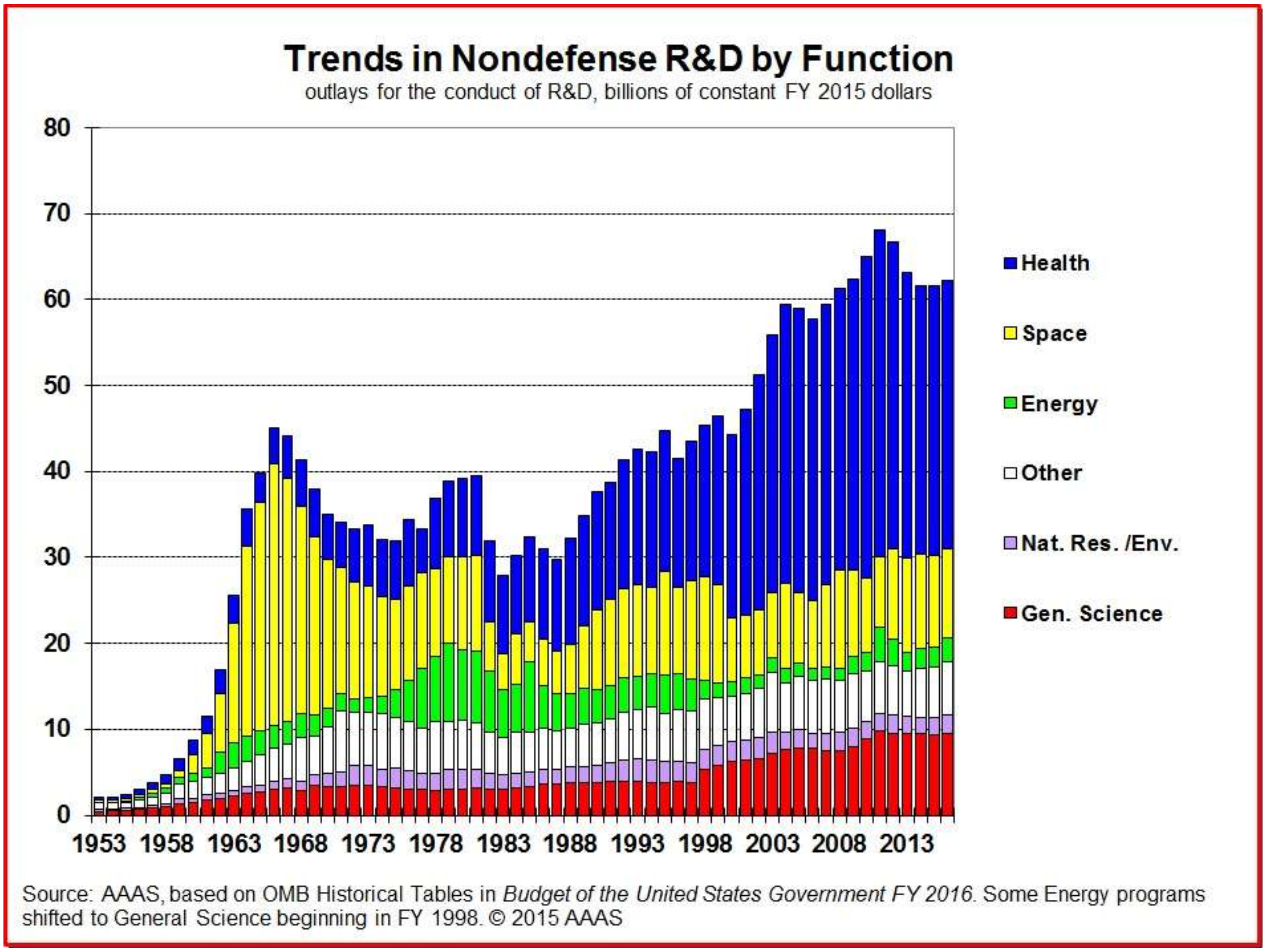

Figure 5 Non-Defense U.S. R&D 1953-2015

Attachment A

Additional excerpts from Dr. John Holdren's (Director, Office of Science and Technology Policy, Executive Office of the President of the United States) written statement to the U.S. House of Representatives Committee on Science, Space, and Technology, given 17 September 2014

<u>Elaboration on the human drivers of global climate change</u>

Scientists have developed good estimates of the magnitudes of both human-caused and natural influences on the global climate (called "forcings" in climate science) since the start of the Industrial Revolution around 1750. The results show that the human influences in this period have far outweighed the natural forcings, as well as internal variability of the climate system. The 2013 IPCC report found, specifically, that the positive forcing (warming influence) attributable to human-caused emissions over the period 1750-2011 was about 80 times as large as the positive forcing from changes in solar irradiance (the largest natural influence) over that period. Studies going back 20 years and more show that increases in globally-averaged temperatures over the last several decades have been too rapid and too sustained to be a result of internal climate variability.

Carbon dioxide (CO_2) is the most important greenhouse gas emitted by humans. Emissions of CO_2 between 1750 and 2011 accounted for 42 percent of the total positive forcings resulting from all human emissions over this period; and current CO_2 emissions are responsible for around
75 percent of the century-scale Global Warming Potential (GWP) of all current human emissions of heat-trapping substances.[18]

In 2012, about 90 percent of global anthropogenic CO_2 emissions came from fossil-fuel combustion and cement production (40% coal, 30% oil, 16% natural gas, 4% cement) and 10 percent from deforestation and other land-use change. Of the "industrial" (fossil fuel and cement) emissions in that year, China accounted for about 29%, the United States for about 15%, the 27 countries of the European Union for about 11%, India for about 6 percent, Russia for about 5 percent, and Japan for about 4 percent. These relatively few

[18] Note: The GWP of an initial emissions pulse of a greenhouse gas is calculated by summing its warming effects over a specified number of years into the future. Because different greenhouse gases have different lifetimes in the atmosphere, the relative importance of their respective emissions at a given time—as measured by GWP—depends on the length of time chosen for those sums. One hundred years is a common choice. Note also that the IPCC's new approach to allocating the responsibility for forcing (as of the 2013-14 assessment) is based on the contribution of emissions of the heat-trapping substances and their precursors between 1750 and 2011, not on the changes in concentrations of the heat-trapping substances as was the approach in the IPCC's previous assessments. The two approaches to allocation give somewhat different numbers because emissions of some substances affect not only their own concentrations but also the concentrations of others.

countries alone, then, accounted for about 70 percent of global industrial CO_2 emissions in 2012.

The second most important greenhouse gas emitted by humans is methane (CH_4). It has a far shorter atmospheric lifetime than that of carbon dioxide, but methane emissions between 1750 and 2011 nonetheless accounted for about 24 percent of the total positive forcings resulting from all human emissions over this period. Part of this contribution is because chemical reactions involving CH_4 lead to increases in tropospheric ozone and stratospheric water vapor. The activities responsible for civilization's methane emissions are, approximately: fossil-fuel production, processing and transport, 30%; animal husbandry, 27%; waste management, 23%; rice cultivation, 10%; and biomass burning, 10%.[12]

Emissions of halogen gases (leaked from a variety of commercial products and industrial uses) accounted for another 9% of the total positive forcing as of 2011, compared to 1750, but about 40 percent of the positive forcing from the halogen gases was cancelled out by the reduction in the stratospheric concentration of ozone caused by their emissions. Emissions of nitrous oxide (from combustion and fertilizer use) contributed about 4% of the total positive forcing up to 2011.

The other major contributor to positive forcing since the beginning of the Industrial Revolution is not a greenhouse gas at all but "black carbon"—heat-absorbing particles emitted primarily by biomass burning and by many two-stroke and diesel engines. Although the atmospheric lifetime of these particles is only days to weeks, their emissions had contributed about 16% of all positive forcing as of 2011, compared to 1750.

The positive forcings from the sources just mentioned are currently being partially offset by negative forcing that comes from reflective and cloud-forming particles that also have increased in concentration in the industrial era. The main sources of these particles are certain oxides of sulfur and nitrogen emitted by fuel combustion. There are strong incentives to reduce those emissions for reasons of public health and the protection of ecosystems from acid precipitation, however, and when this happen the resulting reduction of negative forcing by the associated reflective and cloud-forming particles will "unmask" some of the warming that currently is being offset.

Elaboration on the "hiatus" in global warming

A number of climate-change contrarians have been propagating the claim that there has been no global warming since 1998. This is not correct.

Although the rate of increase in the globally and annually averaged temperature of the atmosphere near the surface has slowed since around 2000[19] compared to the rate of increase

[19] Note: The one year in the top 14 that occurred prior to 2000 was 1998. It was the third or fourth warmest year since 1880 as a result of an unusually powerful El Niño, which boosted the global-average surface temperature well above the trend line. The recent rate of temperature increase can be made to look smaller by "cherry-

over the preceding three decades, near-surface warming of the atmosphere has indeed continued. The 2000s were warmer than the 1990s, and the 2010s so far have been warmer than the 2000s.

Thirteen of the 14 warmest years since decent thermometer records became available (around 1880) have occurred since 2000. During the recent period in which the rate of increase of the average surface air temperature has slowed, moreover, other indicators of a warming planet—shrinkage of Arctic sea ice and mountain glaciers, increased discharges from the Greenland and Antarctic ice sheets, increased ocean temperatures, and sea-level rise—have been proceeding at or above the rates that characterized the preceding decades.

The long-term warming trend resulting from the build-up of heat-trapping gases and particles in the atmosphere is superimposed on a considerable amount of variability—year-to-year and decade-to-decade ups and downs in the global-average atmospheric temperature resulting from variations in solar output, in volcanic activity that injects reflecting particles into the stratosphere, and in ocean circulation patterns that govern how much of the trapped heat goes into the oceans as opposed to staying in the atmosphere. Scientists therefore do not expect the rate of atmospheric warming, which results from the combination of human and natural influences, to be uniform from year to year and decade to decade. Climate models show short periods of slow warming and even cooling within long-term warming epochs, much as we see recently in observations.

The reduced rate of warming since around 2000 is thought to be the result of a partial offsetting, by a combination of natural factors that tended to cool the atmosphere in this period, of the warming influence of the continuing greenhouse-gas build-up. An increase in emissions of sunlight-reflecting particles from an increase in global coal use may also have contributed. Among the natural factors thought to be involved, oceans are likely to have played a major role in slowing atmospheric warming in this period. The oceans normally take up more than 90 percent of the excess heat trapped by anthropogenic greenhouse gases; thus, a small percentage increase in what goes into the ocean can take a large share away from what otherwise would have gone into the atmosphere.

When the variability that has lately slowed surface-atmosphere temperature trends next shifts to contributing warming, of course, it will then reinforce rather than offset the warming influence of the build-up of greenhouse gases. The rate of increase of the global-average surface temperature will then rebound, becoming more rapid, rather than less rapid, than the long-term average.

It is not clear, finally, that all of what has long been called “natural variability” is completely free of human influences. It’s known that the geographic unevenness of anthropogenic global warming (amplified in the Northern Hemisphere by the shrinkage of Arctic sea ice, among other factors), affects atmospheric and oceanic circulation patterns. There is considerable evidence

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picking” the 1998 spike as the new start date for one’s trend line, as a number of contrarians have done to bolster their claim that global warming has stopped.

that the El Niño / La Niña cycle, as well as other patterns that affect how much trapped heat ends up in the oceans rather than in the atmosphere, are being influenced to some extent by anthropogenic global warming.

It has been suggested that the slow rate of recent warming calls into question our understanding of the importance of CO_2 in determining Earth's climate. There is no reason to believe this. Short periods of slow warming and even cooling amidst longer warming epochs are expected and are seen in instrumental records, geologic temperature reconstructions, and in climate-model output. Internal redistributions of energy (as are suspected to be responsible for most of the recent slowdown in atmospheric warming) in no way conflict with our understanding of CO_2 as a dominant driver of long-term changes in Earth's climate.