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The Science Supporting the Climate Action Plan

Chairman Smith, Ranking Member Johnson, and Members of the Committee, I am pleased to be here with you today to discuss the ways in which the Federal Government has incorporated and continues to incorporate rigorous scientific information, insights, and analyses from a diversity of credible bodies into the formulation and implementation of President Obama's Climate Action Plan[1]—hereinafter CAP—to cut carbon pollution in America, prepare the United States for the impacts of climate change, and lead international efforts to address the global climate-change challenge.

The CAP rests, most fundamentally, on scientific and technological understandings, analyses, and judgments in three categories: (1) the natural science of anthropogenic climate change and its impacts on human well-being; (2) technological analysis of the possibilities (including both current status and future prospects) for climate-change mitigation—meaning measures to reduce the pace and ultimate magnitude of the changes in climate that occur—and for increasing preparedness for and resilience against the changes in climate that mitigation fails to avoid; and (3) the economics associated with estimating (a) the costs of mitigation and preparedness/ resilience measures at various levels of implementation and (b) the costs of the harm to human well-being that is not avoided by either mitigation or improved preparedness and resilience.

There is an immense amount of primary, peer-reviewed, published research in all three of these categories, and syntheses characterizing the states of knowledge about them have been and continue to be 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

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[1] President Obama's *Climate Action Plan*, 2013, accessible at: http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf
[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.

These syntheses and many more were drawn upon in the interagency effort, led by the Executive Office of the President (EOP), which developed the elements of the CAP for the President's approval. A particularly compact and accessible digest of the relevant state of knowledge as of early 2013 and a set of recommendations based on it was provided to the President and the EOP in March of that year by the President's Council of Advisors on Science and Technology (PCAST).[9] That report's influence on the Climate Action Plan was considerable, as any reading of the two documents will confirm.

In the remainder of this testimony, I will summarize the insights from the above-listed studies that are most germane to the Climate Action Plan, addressing all three of the science and technology categories mentioned at the outset.

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

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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
[9] PCAST March 2013 letter report to the President on Energy and Climate: http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/pcast_energy_and_climate_3-22-13_final.pdf

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:

(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.[10]
(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 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

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[10] 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)

Climate Assessment. (Some illustrative quotations from a number of the key documents are assembled in Attachment A, submitted with this testimony.)

Elaboration on the human drivers of global climate change

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.[11]

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 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

[11] 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.

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 link between climate change and extreme weather

Weather is what is happening in the atmosphere (temperature, pressure, humidity, wind, precipitation) at a particular time and a particular place. Climate is the pattern exhibited by the weather at a particular place (or region, or the world as a whole) over a period of decades, expressed in terms of average values of weather variables day and night at different times of the year, as well as the statistics of deviations (magnitude and frequency) from these averages.

In general, one cannot say with confidence that an individual extreme weather event (or weather-related event)—for example, a heat wave, drought, flood, powerful storm, or large wildfire—was caused by global climate change. Such events usually result from the convergence of multiple factors, and these kinds of events occurred with some frequency before the onset of the discernible, largely human-caused changes in global climate in the late 20th and early 21st centuries. But there is much evidence demonstrating that extreme weather events of many kinds are beginning to be influenced— in magnitude or frequency—by changes in climate.[13]

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[12] Note: There are large natural sources that add carbon dioxide and methane to the atmosphere and large natural sinks that remove these gases. It is the human sources that have led to an imbalance in sources and sinks overall, however, leading to the build-ups of the atmospheric concentrations of these two gases. The same is true of nitrous oxide. There are no large natural sources of halogen gases, however, and the limited natural sinks for many of these lead to very long atmospheric lifetimes for many of those emitted by human activities.

[13] Note: Increases in magnitude or frequency of extremes that range far beyond historical experience can be attributed to climate change with very high confidence. For example, an analysis provided by the UN's World Meteorological Organization with its 2014 assessment of global climate in the preceding year showed that the

The manifestations of these changes in climate are observable almost everywhere:

- The atmosphere has become warmer, averaged over the year, for the world as a whole and in all but a few individual locations, and it has become wetter (the absolute humidity has increased), averaged over the year, for the world as a whole and in many regions.
- Ocean surface temperatures have risen, averaged over the year, for the world as a whole and in most places, and the depth of the ocean's warm surface layer has increased in some regions.
- The geographic unevenness of the warming[14] is affecting atmospheric and oceanic circulation patterns, although exactly how cannot always be sorted out, currently, from the natural variability in these patterns.

This being so, it is reasonable to say that most weather in most places is being influenced in modest to significant ways by the changes in climate that have occurred as a result of human activities.

A number of changes in extremes of weather and of weather-related events have become evident over the past few decades:

- Extremes of high temperature—both individual hot days and heat waves (periods of unusually high temperature that last for more than five consecutive days)—have become both more frequent and hotter in many regions.
- A larger fraction of total precipitation is occurring in extreme downpours in the United States and many other parts of the world. This is plausibly contributing to an increased risk of flooding in at least some regions.
- Drought has become more frequent and more severe in the American West and in some other historically drought-prone parts of the world.[15]
- Hotter and drier weather in wildfire-prone regions, coupled with earlier snowmelt, mean that the fire season starts earlier in the spring, lasts longer in the fall, and burns more acreage (although there is considerable year-to-year variability in the area burned).
- The intensity of tropical storms is up in some regions (most notably the North Atlantic) but not in others. There is reason to believe, though, that the most powerful of these storms—called hurricanes in the Atlantic and Eastern Pacific and typhoons in the Western Pacific—are becoming more powerful than they otherwise would be because of warmer sea-surface temperature, greater depth of the warm ocean surface layer, and higher atmospheric moisture, and that they also are becoming more devastating than they otherwise would be when they make landfall, because their storm surges occur on top of a mean sea level made higher by global warming.
- There is evidence that conditions conducive to severe thunderstorms are becoming more prevalent in the Eastern United States. Because of high year-to-year variability, however, one cannot say at this point whether recent observed increases in thunderstorm activity are

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Australian country-wide temperature record set in 2013 would have been "virtually impossible" as a result of natural variability alone.

[14] Note: For well understood reasons, the warming produced by the build-up of greenhouse gases is greater over land than over the oceans, and greater in the far North than in the mid-latitudes and tropics.

[15] Note: That drought can increase in some parts of a world that is getting more precipitation on the average is not a paradox. Global climate change is nonuniform. Precipitation is down in some places while up in others, and earlier melting of snowpack and higher losses of moisture to evaporation from soil and reservoirs contribute to low stream flows and soil drying in summer in many regions.

attributable to climate change. There is as yet not any evidence that tornadoes have increased in frequency or intensity as a result of global climate change.

There are good scientific explanations, moreover, supported by measurements, of the mechanisms by which the overall changes in climate resulting from the human-caused build-up of heat-trapping substances are leading to the observed changes in weather-related extremes. Accordingly, it is expected that the kinds of extremes already observed to be increasing will continue to increase in magnitude and/or frequency going forward, unless and until the build-up of heat-trapping substances driven by emissions from human activities is brought to a halt.

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 compared to the rate of increase 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.[16] 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

[16] 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-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.

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 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.

Quantitative measurements and projections

Two important questions germane to assessing how much action is warranted to address climate change are these: (1) Just how big are the changes in climate that have already occurred, measured against the yardstick of pre-industrial conditions? (2) How much bigger are the changes likely to become in the decades ahead under a range of assumptions about actions taken going forward (or the lack of them)?

Those questions are briefly addressed in what follows by reference to recent measured values of some key indicators and projections of the values those indicators are expected to reach by 2050 and 2100 under scenarios developed by the IPCC to explore the consequences of minimal versus maximal global mitigation actions going forward. The range of possibilities assessed by the IPCC is spanned by scenarios labelled RCP2.6 on the maximal-action side and RCP8.5 on the minimal-action side,[17] and these two scenarios as analyzed in the IPCC's 2013 and 2014 reports are the source of the projections provided below.

Increase in atmospheric carbon dioxide. As noted above, CO_2 is the most important of all the heat-trapping gases added directly to the atmosphere by human activities.

[17] In the IPCC's terminology, RCP stands for Representative Concentration Pathway, and the numbers represent the approximate total net forcing from anthropogenic influences in 2100 (accounting for negative as well as positive contributions) under the indicated scenario, i.e., 2.6 watts per square meter of Earth's surface in RCP2.6 and 8.5 watts per square meter in RCP8.5.

- *Measurements*. The average concentration of CO_2 in the atmosphere in 1750 was about 278 parts per million by volume (ppmv). In 2013, the corresponding figure was 396 ppmv. That's an increase of 42 percent. Ice-core studies show that the 2013 value is the highest concentration of atmospheric CO_2 experienced on Earth in the last 800,000 years.
- *Projections*. In the IPCC's minimal-action/high-emissions scenario (RCP8.5) the CO_2 concentration reaches 540 ppmv by 2050 and 936 ppmv by 2100. In the maximal-action/low-emissions scenario (RCP2.6), the figure is 421 ppmv in 2100.

<u>Temperature</u>. The single most informative index of the state of the global climate is the annually and globally averaged temperature of the atmosphere near Earth's surface. This average has been directly computable from thermometer measurements around the world since the mid to late 19th century.[18]

- *Measurements*. According to the IPCC's 2013 report, the global average surface temperature for 2000-2009 was 0.78±0.06 °C (1.40±0.11°F) warmer than the average for 1850-1900.[19] The 2014 National Climate Assessment gives the increase in average surface temperature for the contiguous United States between 1895 and 2012 as 0.89±0.17 °C (1.6±0.3 °F).
- *Projections*. In the IPCC's 2013 RCP8.5 scenario, the global average surface temperature for 2046-2055 is 2.6±0.6 °C above the 1880-1899 average and for 2086-2095 it is 4.3±1.0 °C 7.6±1.8 °F) above the 1880-1899 average. For RCP2.6, the values are 1.6±0.6 °C for 2046-2065 and 1.6±0.7 °C in 2081-2100.

<u>Sea level</u>. Changes are not uniform across the globe, due to nonuniform heating and effects of Earth's rotation, winds and ocean currents, gravitational anomalies, and continental subsidence and uplift. The average change is informative about overall trends, however.

- *Measurements.* According to the IPCC (2013), global mean sea level in 2010 was about 0.2 meters (8 inches) higher in 2010 than in 1900 and about 0.3 meters higher than its 1750 value. The rate of increase since 1990 has been double the average for the 20th century.[20]
- *Projections.* In the IPCC's RCP8.5 scenario, the <u>additional</u> increase by 2100 is projected at 0.7±0.3 meters (28±13 inches), with further large increases following inevitably. For RCP2.6, the additional increase by 2100 is projected at 0.4±0.15 meters (16±6 inches). As noted above, NOAA's range of possibilities for 2100 extends even higher.

<u>Increase in ocean acidity</u>: Part of the excess CO_2 added to the atmosphere by human activities is absorbed by the ocean, where it combines with H_2O to make carbonic acid (H_2CO_3). The resulting increase in the acidity of sea water (decline in its pH) imperils many of the organisms that make their shells or skeletons from calcium carbonate (corals, oysters, zooplankton).

- *Measurements.* The global-average pH of ocean surface water has declined by about 0.1 pH unit since 1750, which corresponds to a 26 percent increase in hydrogen-ion concentration. (Because of regional variations in ocean chemistry, the range is 20-35 percent.)
- *Projections.* In the IPCC's RCP8.5 scenario, ocean-surface pH falls another 0.35 pH unit by 2100, corresponding to a further 2.2-fold increase in hydrogen-ion concentration. Under RCP2.6, pH in 2100 is only 0.05 units below the current value, representing a 12 percent increase in hydrogen-ion concentration compared to today.

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[18] Note that small changes in the globally averaged atmospheric temperature near the surface are associated with large changes in the spatial and temporal patterns of temperature, precipitation, etc., that constitute climate. This is clear from the substantial changes in these patterns already being observed after an increase of only 0.8°C.

[19] IPCC, *Climate Change 2013: The Physical Science Basis*, p 37.

[20] Ibid, p 49

The numbers presented above underscore a key point made by the authors of the Third U.S. National Climate Assessment:

> *As the impacts of climate change are becoming more prevalent, Americans face choices. Especially because of past emissions of long-lived heat-trapping gases, some additional climate change and related impacts are now unavoidable. This is due to the long-lived nature of many of these gases, as well as the amount of heat absorbed and retained by the oceans and other responses within the climate system. The amount of future climate change, however, will still largely be determined by choices society makes about emissions. Lower emissions of heat-trapping gases and particles mean less future warming and less-severe impacts; higher emissions mean more warming and more severe impacts.*[21]

Technological Analysis of the Possibilities for Remedial Action

Mitigation

The importance of a technology strategy to address the challenges of climate change has been recognized since the 1990s. One early and seminal study, published in 1992 by the Committee on Science, Engineering, and Public Policy (COSEPUP) of the National Academy of Sciences and National Academy of Engineering,[22] explicitly addressed technological options for reducing emissions of greenhouse gases, including CO_2, and the need for further mitigation research and development (R&D) in several categories, including energy management in residential and commercial buildings, industrial energy management, transportation energy management, and energy supply systems. These basic energy-consuming sectors of the economy have continued to form the analytical framework for proposals to mitigate the human causes of global climate change.

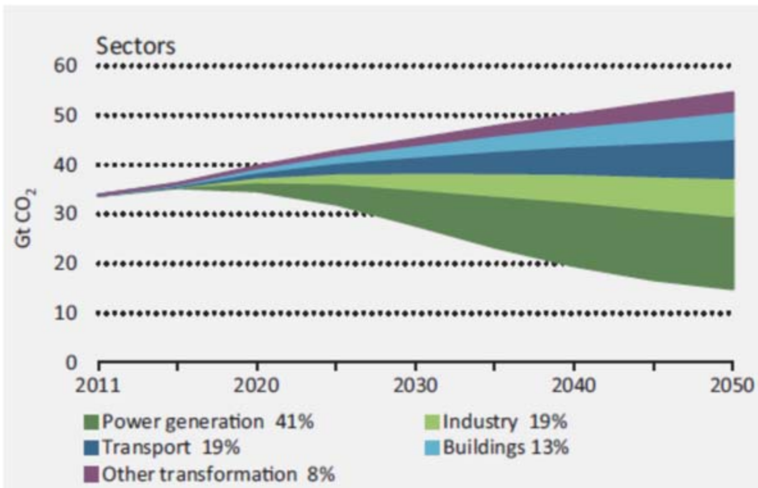
As the understanding of the potential for anthropogenic greenhouse gas emissions to cause dangerous interference with the global climate system has matured, numerous scenarios have been developed (by the IPCC, as mentioned above, and many other groups) to relate combinations of potential mitigation actions, and their effects on future emission trajectories, to the resulting changes in the projected increase in global average temperatures. One much-analyzed "business as usual" scenario, involving a continuation of current greenhouse gas emission trends, is known as the 6-Degree Scenario, because these extended current trends would result in at least a 6-degree Celsius rise in long-term global average temperatures. (Warming at 2100 would be about 4 degrees C. This scenario is similar to the IPCC's RCP8.5 scenario, described above.) This amount of global warming is widely believed to be associated with severe and irreversible impacts, such as large-scale extinctions and, over time, catastrophic sea-level rise. A second scenario, known as the 2-Degree Scenario, describes an emission trajectory that recent climate science research indicates would give at least a 50 percent chance of limiting average global temperature increases to 2 degrees Celsius, the target agreed at the 2009 Conference of the

[21] *Climate Change Impacts in the United States*, 2014 [Third U.S. National Climate Assessment], p. 13.

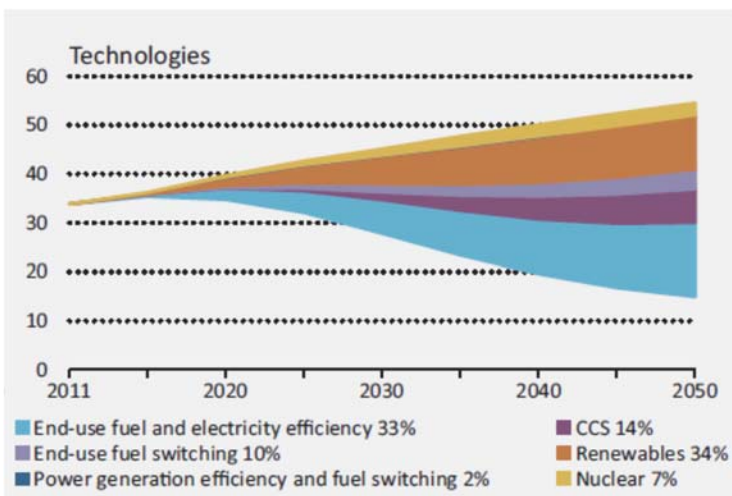
[22] Committee on Science, Engineering, and Public Policy of the National Academy of Sciences and National Academy of Engineering, *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base*. 1992. Washington, D.C.: National Academy Press.

Parties to the UN Framework Convention on Climate Change. (This scenario resembles the IPCC's RCP2.6.)

The following figure shows the difference between emissions of greenhouse gases under the two such scenarios, as estimated by the most recent *Energy Technology Perspectives* report of the International Energy Agency (IEA). The top of the colored bands describes the likely growth of emissions out to 2050 in the 6-Degree Scenario. The bottom line represents the level of emissions needed to achieve the 2-Degree Scenario. The colored bands represent the contributions of improvements in various energy-consuming sectors to avoid the 6-Degree Scenario and achieve the 2-Degree Scenario. Like the earlier COSEPUP report, this figure shows that technological changes to avoid dangerous interference in the global climate system will require contributions from the four key energy sectors of buildings, industry, transport, and power generation.[23]



The classes of technologies that could be deployed in these sectors to achieve the 2-Degree Scenario have also been modeled by the IEA, and are depicted in the next figure.[24]



While IEA reports are not official documents of the U.S. government, they are the result of strong international technical collaboration and analysis by leading scientific and engineering

[23] International Energy Agency, *Energy Technology Perspectives 2014*, 30.
[24] *Ibid.*

experts from developed countries, including the United States. The *Energy Technology Perspective* reports and their technology roadmaps show that it is possible to construct energy pathways that are likely to avoid exceeding the 2-degree Celsius threshold for global temperature increase, while maintaining a secure and affordable energy system in the long run. The IEA even projects that its particular 2-Degree Scenario retains an important role for fossil energy in an increasingly sustainable global energy system. A variety of other authoritative analyses, including those in the IPCC's 2007 and 2013-14 reports, echo these general findings: namely, that economically and environmentally sustainable energy systems for the future can be constructed based on substantial improvements in energy efficiency and greater shares of renewable and nuclear energy, along with advanced fossil-fueled power plants with carbon capture and storage.[25]

The energy R&D programs of the U.S. Department of Energy (DOE) have long included major attention to these areas, and all of them are well represented in recent DOE budgets. In November 2011, DOE released its first-ever Quadrennial Technology Review (QTR), advocated by PCAST a year earlier[26] as a way to ensure that relevant options were all being appropriately tracked and supported to ensure their timely development to their full potential. In that review, six thrusts were deemed essential to an energy future that both strengthens U.S. competitiveness and protects the climate:

- Increase vehicle efficiency;
- Electrify the vehicle fleet;
- Deploy alternative liquid fuels;
- Increase building and industrial efficiency;
- Modernize the national electrical grid; and
- Deploy cleaner electricity sources.[27]

The Administration has strong efforts underway in each of these domains.

There is, then, a strong analytical base pointing to an array of improved and new energy technologies that can be brought to bear to reduce greenhouse-gas and black-carbon emissions in a manner that supports both energy security and economic competitiveness. That is not to say, however, that these technologies will materialize automatically in the quantities and on the time scale required. The Third National Climate Assessment highlighted the need for careful attention to the policy mechanisms that could be used to foster the development and implementation of such technologies; and analyses of the costs, benefits, tradeoffs, and synergies associated with different actions and combinations of actions to deploy them.[28] The CAP has taken those insights, too, on board, and its implementation will benefit from them. It is clear, though, that technology offers possibilities for reducing emissions of heat-trapping substances even beyond what the CAP will achieve, and the science makes it clear that such further reductions will be essential. The help of Congress ultimately will be required if the full potential of technology in this domain is to be realized.

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[25] See the references cited in Footnotes 2 and 3, as well as Johansson, T.B., A. Patwardhan, N. Nakicenovic, and L. Gomez-Echeverri, *Global Energy Assessment – Toward a Sustainable Energy Future.* 2012. Cambridge University Press and the International Institute for Applied Systems Analysis.

[26] President's Council of Advisors on Science and Technology, 2010. *Report to the President on Accelerating the Pace of Change in Energy Technologies through an Integrated Federal Energy Policy*, pp 10-11.

[27] U.S. Department of Energy, 2011. *Report on the First Quadrennial Technology Review*, ii.

[28] *Climate Change Impacts in the United States*, 2014 [Third U.S. National Climate Assessment], p711.

Preparedness and resilience

Although the importance of a technology strategy for climate-change mitigation has been apparent since the 1990s, the importance of a companion technology strategy to support climate-change adaptation, preparedness, and resilience has come into view only in the last few years. The first major international study to give equal weight to mitigation and adaptation—the report of the UN Special Experts Group on Climate Change and Development[29]—came out only in 2007. The U.S. National Academies' report on *America's Climate Choices* noted in 2010 that:

> *While options available to the nation for adapting to the impacts of climate change have in many cases been identified, the scientific understanding of the effectiveness of these options is lacking, given that climate change is likely to pose challenges beyond those that have been addressed in the past as adaptations to climate variability. Thus, the need for scientific and technological advances is pervasive across the field of climate change adaptation research. ... Recently, examination of the Climate Change Science Program has shown that investment in "human dimensions research," including but not mainly oriented toward adaptation, and non-research expenditures on decision support represent about 2 percent of the total climate change research effort (NRC, 2009c). Investment in adaptation research is only a fraction of that 2 percent.*[30]

This situation has since substantially changed, as can be seen in the current 10-year strategic plan for the USGCRP, which was approved and published in 2012. Each of its four key strategic goals (i.e., advance science, inform decisions, conduct sustained assessments, and communicate and educate) focus on the needs to build and properly utilize a broad base of scientific and technological information to support adaptation actions and strategies.[31]

The technological possibilities for contributing to this goal extend across the spectrum of societal infrastructures that will be affected by a changing climate, as is described in more detail below. In these areas, as the National Research Council observed, the first technological steps towards addressing adaptation needs may be extensions of existing options for dealing with climate variability or extreme events, differing mainly in the scope of implementation, frequency of application, and the intensity of effort. It is also possible, though, that future climate change "may well exceed the range of current climate variability and extreme events; thus, novel adaptations are very likely to be needed, especially in the event of tipping points and/or abrupt changes."[32]

A primary and general technological need associated with adapting to climate change is in the area of technologies for collecting, analyzing, and disseminating information. Enhancements to monitoring systems will be needed for adequate detection of stresses and changes in both natural systems and societal infrastructure in order to identify, at an early stage, potential needs for adaptation. For built systems, this would include an analysis of engineering thresholds of current infrastructures, so that there is a better understanding of their current resilience to climate-change

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[29] UN Special Experts Group (UNSEG), *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable*, United Nations Foundation, 2007.
[30] National Research Council, 2010. *America's Climate Choices: Adapting to the Impacts of Climate Change*, p. 203.
[31] National Science and Technology Council. *The National Global Change Research Plan 2012-2021,* p. xvi.
[32] National Research Council, 2010. *America's Climate Choices: Adapting to the Impacts of Climate Change*, p. 213.

impacts.[33] There is a related need to improve understanding of the engineering inter-dependencies across the infrastructures and services fundamental to a vibrant economy and the degree to which these infrastructures and these services will be altered by climate change.[34] Once this information is gathered and analyzed, there are technological challenges in ensuring that the information is synthesized and disseminated in formats that can be readily used by decision-makers in both governmental and nongovernmental settings.

With respect to specific key sectors of the U.S. economy, there is a variety of technological opportunities that could boost their resilience and meet needs created by climate changes that can no longer be avoided. The following sectoral examples illustrate some of these possibilities.

Water. As climate change increases stress on water supplies, there may be significant opportunities for new technologies that give greater insight into the real-time status of ground and surface waters,[35] as well as for technologies that would improve the efficiency of water use in applications such as energy production.[36] In some places in the world, groundwater withdrawals are leading to significant subsidence that is exposing major cities to greater flooding from rivers or the ocean. Water supply technologies that can serve as an alternative to such "groundwater mining" may help reduce the potential for flooding associated with heavy downpours or sea-level rise.[37] Opportunities also exist to utilize technology to better manage surface-water resources. For example, some water agencies are developing approaches that inform flood-control operations using improved weather forecasts and soil-moisture monitoring, in turn preserving more water for consumers to use.

Agriculture. Climate change poses a major challenge to U.S. agriculture and has already led to steps farmers have taken to adapt to changes in temperature and precipitation. The Third National Climate Assessment found that "In the longer term, however, existing adaptive technologies will likely not be sufficient to buffer the impacts of climate change without significant impacts to domestic producers, consumers, or both. New strategies for building long-term resilience include both new technologies and new institutions to facilitate appropriate, informed producer response to a changing climate."[38] Such technologies may include new forms of sustainable irrigation in agriculture;[39] developing/breeding crops that can thrive in changed ecosystems and places,[40] including salt-tolerant crops;[41] and focusing on technologies that can help marine aquaculture to adapt to increasing ocean acidification.[42]

Natural Ecosystems. Beyond the benefits of agricultural and intensely managed forest eco-systems, less intensely exploited ecosystems also provide many benefits to society, including clean water, habitat that supports valuable biodiversity, food from wild fish stocks, and

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[33] National Research Council, 2010. *America's Climate Choices: Adapting to the Impacts of Climate Change*, p. 205.
[34] Water Utility Climate Alliance, 2013. "National Climate Resiliency Initiative 2013."
[35] *Climate Change Impacts in the United States*, 2014 [Third U.S. National Climate Assessment], p. 89.
[36] *Climate Change Impacts in the United States*, 2014 [Third U.S. National Climate Assessment], p. 265, 267.
[37] Brown, S., et al., 2014. "Shifting Perspectives on Coastal Impacts and Adaptation," *Nature Climate Change* 4: 752-753.
[38] *Climate Change Impacts in the United States*, 2014 [Third U.S. National Climate Assessment], p. 161.
[39] National Research Council, 2010. *America's Climate Choices: Adapting to the Impacts of Climate Change*, p. 68.
[40] *Ibid.*
[41] National Research Council, 2010. *America's Climate Choices: Adapting to the Impacts of Climate Change*, p. 210.
[42] *Climate Change Impacts in the United States*, 2014 [Third U.S. National Climate Assessment], p. 562.

opportunities for tourism and recreation.[43] Such ecosystems also have the ability to enhance the resilience of communities to climate change and extreme weather. For example, salt marshes, sand dunes, and barrier islands can serve as "nature's defenses", helping to shield homes and businesses from storm surge and coastal flooding.[44] Technological approaches are being developed to enhance integration of these nature-based ("green") approaches with built ("gray") infrastructure to enhance community resilience. Technological approaches are also being developed to better observe and forecast changing ocean conditions to help resource managers and ocean industries reduce impacts and increase resilience.[45]

Transportation. The Department of Transportation (DOT), in partnership with states and communities, is already advancing integration of climate information to minimize the effects of extreme weather and climate change on critical transportation infrastructure. In 2010 and 2011, DOT's Federal Highway Administration (FHWA) supported state Departments of Transportation and Metropolitan Planning Organizations' efforts to pilot approaches for conducting climate change vulnerability and risk assessments. FHWA helped to support projects in San Francisco Bay, coastal and central New Jersey, Hampton Roads, Virginia, the State of Washington, and the Island of Oahu, Hawaii. Informed by these pilot efforts, DOT is now supporting 19 Climate Resilience Pilots across the country. In addition, DOT is working with its partners in Mobile, Alabama, to conduct a vulnerability assessment of transportation infrastructure. Results of the work, including project level engineering analyses, as well as transferable climate risk management tools for use in other locations, should be available later this year. Going forward, there may be opportunities for new materials and technologies to make transportation systems less vulnerable to damage from temperature increases and water submergence. New technologies may also help in improving the function of transportation systems for emergency response and evacuation.[46]

Built Environment. A variety of technological efforts are underway around the world to address vulnerabilities of coastal communities to sea-level rise. They include projects to erect barriers; increase land elevation; stabilize erodible shores; harden facilities; and to develop rigorous methodologies for assessing the costs, benefits, and broader implications of these engineered solutions. Notable examples include the Thames Estuary 2100 Project--which is looking for the best ways of protecting London from tidal flooding over the next century and beyond--and efforts in the Netherlands, Maldives, and Singapore for claiming or building up new land.[47] In the United States, under the CAP, Federal agencies are integrating climate and sea-level rise considerations into rebuilding and recovery efforts such as those being undertaken in the aftermath of Hurricane Sandy. In addition, cities like New York City are upgrading existing buildings to be resilient against storm surges, as part of comprehensive planning for adapting these key urban centers to expected climate change.[48]

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[43] Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-Being: Synthesis*. World Resources Institute, Washington, DC.
[44] Arkema et al. 2013. Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change* 3: 913-918.
[45] *Climate Change Impacts in the United States*, 2014 [Third U.S. National Climate Assessment], p. 89.
[46] National Research Council, 2010. *America's Climate Choices: Adapting to the Impacts of Climate Change*, p. 209.
[47] Brown, S., et al., 2014. "Shifting Perspectives on Coastal Impacts and Adaptation," *Nature Climate Change* 4, 753-754.
[48] City of New York, 2013. PlaNYC: A Stronger, More Resilient New York, Chapter 4: Buildings.

Energy. The resilience of the electrical grid to weather and climate impacts may be increased by developing and implementing better grid sensors and equipment that enable adaptive switching of loads in cases of severe weather.[49] The adaptation of the electrical grid to climate change may also be improved by technologies that facilitate the deployment of "microgrids" to increase the resilience of the grid in specific areas.[50]

The Economics of Action and Inaction

The President's Climate Action Plan highlighted the sobering finding that changes in global climate that have been connected by science with increased emissions of greenhouse gases "come with far-reaching consequences and real economic costs." This June 2013 statement was based on the then-available subset of the peer-reviewed syntheses of the natural science of climate change and its impacts referenced in the first section of this testimony. The key question for economic analysis, bearing on decisions that are taken with respect to investments in climate-change mitigation and adaptation, is how the costs of these remedial actions compare to the costs of failing to take them (imposed by climate-change impacts that are not avoided by mitigation or ameliorated by improved preparedness and resilience).

Serious attempts to answer that question have been underway for some two decades. It is made particularly difficult by a number of factors, most notably: the uncertainties surrounding the exact character and magnitude of the climate-change impacts to be expected at global-average surface temperatures much higher than today's; the difficulty of monetizing many kinds of potential climate-change impacts—sea-level rise, ocean acidification, ecosystem disruptions, forced migration—even if they are reasonably well characterized; the uncertainties surrounding the future costs of many of the most promising technologies for reducing emissions from the global energy system; a baseline for energy-cost comparisons that is distorted by fossil-fuel subsidies and the free ride these fuels have enjoyed by being able to use the atmosphere as a waste dump for their green-house-gas emissions; and disagreements about the appropriate discount rates for reducing, to comparable present values, the costs of future remedial action and future climate-change impacts.

In the 1990s, attempts to compare the costs of action and inaction on climate change fell largely into two categories: studies arguing that, since the costs of taking action are relatively well defined and, at least initially, close in time, while the costs of inaction are highly uncertain and largely distant in time, it is reasonable to delay action; and studies arguing that the potentially catastrophic "downside" risks of extreme climate change were so terrible, even if decades or centuries away, that any prudent society would invest the relatively modest sums needed to significantly reduce those risks, as a form of "insurance".[51]

Since then, analyses attempting to quantify the costs of action and inaction have become more widespread and sophisticated, with the values obtained for both (under a variety of assumptions)

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[49] Hoffman, P.A. 2014. "How Synchrophasors are Bringing the Grid into the 21st Century." http://energy.gov/articles/how-synchrophasors-are-bringing-grid-21st-century

[50] National Research Council, 2010. *America's Climate Choices: Adapting to the Impacts of Climate Change*, p. 74.

[51] See, e.g., W. D. Nordhaus, *Economic Journal*, vol 101, pp 920 ff, 1991; W. D. Nordhaus, *Managing the Global Commons: The Economics of the Greenhouse Effect*, MIT Press, 1994; G. Yohe, *Global Environmental Change*, vol 6, pp 87 ff, 1996.

tending to cluster in the range of 0.5 to 5 percent of global GDP in 2030, 2050, and 2100.[52] Despite this apparent symmetry, a growing consensus has emerged in recent years, among economists and others studying this matter, that the case for making substantial investments in climate-change mitigation and preparedness/resilience—and sooner rather than later—is compelling.[53]

There are several reasons for this:

1. The scientific evidence has been building that, as the global-average surface temperature gets to two degrees Celsius and more above the 1850-1900 level, the chances of truly unmanageable types and magnitudes of climate-change impacts becomes unacceptably high. (It is instructive that, the last time the Earth's temperature was that high was 130,000 years ago, and the sea-level height that came to equilibrium with that temperature was between 5 and 10 meters higher than today. [54]) The possibility of these kinds of impacts has not been adequately taken into account in existing cost-of-inaction estimates, because nobody knows how to do it in a rigorous way, and the result is that the costs of inaction have been underestimated.
2. Even a few more years' delay in taking aggressive action to reduce the greenhouse-gas emissions of the major emitting nations will make it impossible to avoid exceeding the 2°C mark and extremely costly even to avoid exceeding 3°C. (Studies by the IPCC, the World Energy Conference, the U.S. National Academies, and others have shown that, from this point, delay in taking action makes any target in the 2-3°C range much more expensive to reach.[55])
3. Most past attempts to project future costs of environmental-control technologies have yielded numbers that turned out, in the course of time, to be overestimates because the use of market mechanisms allows for technology paths that minimize costs (e.g., acid rain program). There is a wide-spread suspicion that to the extent that market mechanisms are used, the same maybe true in the case of technologies to reduce emissions of greenhouse gases and black carbon.
4. Many of the most attractive measures for reducing emissions, as well as many of the measures being contemplated to increase preparedness for and resilience against the changes in climate that are not avoided, can carry very substantial co-benefits for public health (e.g.,

[52] See, e.g., McKinsey and Company, *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abate Cost Curve*, 2009; Intergovernmental Panel on Climate Change (IPCC) 2007; Edenhofer et al., *The Economics of Decarbonization*, Potsdam Institute for Climate Impact Research, 2009; and 2013-2014 IPCC Fourth and Fifth Assessments, reports of Working Group III, accessible at: http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1

[53] See, e.g., Nicholas Stern (ed.), *The Economics of Climate Change: The Stern Review*, Cambridge University Press, 2007; Martin Weitzman, "On modeling and interpreting the economics of catastrophic climate change", *The Review of Economics and Statistics*, vol 91, no 1, pp 1-19; F. Ackerman et al., "The need for a fresh approach to climate-change economics", in *Assessing the Benefits of Avoided Climate Change: Cost-Benefit Analysis and Beyond*, 2010; Benjamin Crost and Christian Trager, "Optimal CO_2 mitigation under damage risk evaluation", *Nature Climate Change*, vol. 4, pp 631-636, 2014; Council of Economic Advisors, *The Cost of Delaying Action to Stem Climate Change*, Executive Office of the President of the United States, July 2014; M. R. Bloomberg, H. M. Paulson Jr., T. F. Steyer, *et al.*, *Risky Business: The Economic Risks of Climate Change in the United States*, June 2014, http://riskybusiness.org/uploads/files/RiskyBusiness_Report_WEB_09_08_14.pdf

[54] IPCC, *Climate Change 2013: The Physical Science Basis*, p. 46. No one is suggesting that sea levels in these ranges could be reached in this century, but Earth's history suggests that's where we're headed in the long run if we can't avoid going beyond 2°C and staying there.

[55] See for example IPCC AR5 Working Group 3 Summary for Policymakers Table SPM.2. See also IEA 2014*, op. cit.*, and Council of Economic Advisors, July 2014, *op cit.*

by reducing conventional air pollution) and for other societal values. These co-benefits have often not been included in the comparisons of the cost of action and cost of inaction that have been done, leading to an underestimate of the benefits of action.

Reflection of the foregoing in the CAP

President Obama has been committed, from the beginning of his Administration, to the rigorous use of the best available scientific and technical information in formulating policy, including, of course, policy to address the threats from climate change. It should not be surprising, then, that the bodies of scientific and technical knowledge and judgment summarized in the foregoing are robustly and appropriately reflected across all elements of the CAP and continue to underpin the CAP's implementation. Specifically:

- An up-to-date understanding of the natural science of anthropogenic climate change and its impacts on human well-being provides (a) the motivation for seeking to develop a cost-effective plan to reduce those impacts; (b) the sense of urgency for doing so at once rather than waiting; (c) the understanding that such a plan must include not only measures to reduce the emissions that are driving global climate change but also measures to increase preparedness for and resilience against the changes in climate that can no longer be avoided; (d) the detailed knowledge of the sources of the offending emissions and the character of society's vulnerabilities that allows appropriate specificity in designing a plan; and (e) the recognition that any U.S. plan must include a component designed to bring other countries along. These are the most basic underpinnings of the CAP.

- An up-to-date understanding of technological possibilities for mitigation and preparedness/ resilience reveals that there indeed exists a wide range of existing and developable options for cutting the carbon pollution that is driving climate change and for better preparing society to deal with the changes that materialize. The available technical insights about these options have enabled the CAP to focus specifically on enabling and incentivizing progress on the development and implementation of the most promising ones, both for emissions reductions and for building preparedness and resilience

- An up-to-date understanding of the results of economic assessments of the costs of taking actions of these sorts versus the costs of inaction provides the confidence that moving ahead now is the right thing to do and, more specifically, has provided the basis for the CAP's focus on those options that are most clearly cost-effective and that bring significant co-benefits. Because the CAP focuses only on the "low-hanging fruit" that is within reach without action by Congress, the costs of implementing it will be relatively low and, indeed, could well be completely repaid by the co-benefits (see below).

Some specifics of application of these insights in the CAP

With respect to actions that will lower emissions of heat-trapping carbon pollution, the CAP contains initiatives to make new energy technologies more economic by reducing barriers to their implementation (for example, through accelerated permitting of clean energy projects and streamlining for other Federal programs) and through regulatory actions for which there is an important role for the calculation of economic costs and benefits, especially with regard to implementation of specific parts of the CAP. For example, in the case of EPA's proposed rules to reduce carbon emissions from existing power plants, EPA's estimate of monetized benefits and compliance costs shows that, in 2030, the combination of climate benefits and air-pollution health co-benefits from the proposed rule will total as much as $93 billion in constant dollars in 2030, while the annual compliance costs net of electricity consumption reduction is estimated to total $8.8 billion.

Other elements of the CAP are also being crafted in ways that generate monetized benefits that exceed any compliance costs. For example, the CAP calls for higher fuel economy standards for heavy-duty vehicles manufactured after model year 2018. This proposal is intended to follow on to a similar set of standards for heavy-duty vehicles for model years 2014 through 2018 that will result, by model year 2018, in a new semi-truck that will save its operator enough to pay for the technology upgrades in under a year and then realize net savings of $73,000 through reduced fuel costs over the truck's useful life.

The energy-efficiency standards that are being encouraged under a new goal outlined in the CAP provide another example of how economic analysis is shaping the CAP's implementation. The underlying law governing these energy efficiency standards, the Energy Policy and Conservation Act of 1974, provides that any new or revised efficiency standard must be designed to achieve the maximum improvement in energy efficiency that is determined to be technologically feasible and economically justified. In order to be found to be economically justified, the benefits of the rule must outweigh its burdens. In carrying out this analysis, the DOE examines impacts on manufacturers; impacts on consumers; impacts on competition; impacts on utilities; national energy, economic and employment impacts; and impacts on the environment and energy security.

Regarding activities to prepare the United States for the impacts of climate change, the CAP outlines a series of measures that also have common-sense utility as well as significant economic benefits. They include efforts to encourage and support smarter, more resilient investments, including through agency grants, technical assistance, and other programs, in sectors from transportation and water management to conservation and disaster relief. In a year in which moderate to severe drought has covered a large area of the United States[56] continuously from the West Coast[57] to the Great[58] Plains[59], with two areas of extreme to exceptional drought in the California-Nevada[60] region and in the Southern Plains[61] centered in northern Texas, there are real economic benefits to helping communities to prepare for droughts and reduce drought impacts, as the Climate Action Plan does through its launch of a National Drought Resilience Partnership. In addition, Executive Order 13653 (issued under the CAP) has charged the Department of the Interior (DOI), the U.S. Department of Agriculture (USDA), NOAA, the EPA, the Federal Emergency Management Agency (FEMA), and the U.S. Army Corps of Engineers (USACE), among others, to identify additional opportunities for enhancing the resilience of the Nation's watersheds, natural resources, and ecosystems in the face of climate change through potential changes to their land- and water-related policies and programs. Agencies are building on efforts already completed or underway, as outlined in agencies' climate change adaptation plans, as well as recent interagency climate adaptation strategies, such as the National Action Plan: Priorities

[56] Source: NOAA: http://www1.ncdc.noaa.gov/pub/data/cmb/sotc/drought/2014/07/20140729_usdm.png
[57] Source: NOAA: http://www1.ncdc.noaa.gov/pub/data/cmb/sotc/drought/2014/07/20140729_west_trd.png
[58] Source: NOAA: http://www1.ncdc.noaa.gov/pub/data/cmb/sotc/drought/2014/07/20140729_high_plains_trd.png
[59] Source: NOAA: http://www1.ncdc.noaa.gov/pub/data/cmb/sotc/drought/2014/07/20140729_south_trd.png
[60] Source: NOAA: http://www1.ncdc.noaa.gov/pub/data/cmb/sotc/drought/2014/07/20140729_west_trd.png
[61] Source: NOAA: http://www1.ncdc.noaa.gov/pub/data/cmb/sotc/drought/2014/07/20140729_south_trd.png

for Managing Freshwater Resources in a Changing Climate; the National Fish, Wildlife, and Plants Climate Adaptation Strategy; and the resilience efforts outlined in the National Ocean Policy Implementation Plan. Collectively, these efforts will help to safeguard the nation's valuable natural resources in a changing climate.

Conclusion

In summary, the scientific and technological literature and analyses described herein make clear the case for urgent action against climate change and are clearly and pervasively reflected in the President's Climate Action Plan. Of course, there is still more that could and should be done that would require the support of the Congress. I hope that this will be forthcoming.

I thank the Committee for its interest in this critically important issue. I will be pleased to take any questions Members may have at this time.

Attachment A

<u>Recent Relevant Quotes from Authoritative Sources</u> (inverse chronological order)

U.S. Global Change Research Program, Third U.S. National Climate Assessment, *Climate Change Impacts in the United States*, May 2014 http://nca2014.globalchange.gov

> *Long-term, independent records from weather stations, satellites, ocean buoys, tide gauges, and many other data sources all confirm that our nation, like the rest of the world, is warming. Precipitation patterns are changing, sea level is rising, the oceans are becoming more acidic, and the frequency and intensity of some extreme weather events are increasing. Many lines of independent evidence demonstrate that the rapid warming of the past half-century is due primarily to human activities.*
>
> *Human-induced climate change means much more than just hotter weather. Increases in ocean and freshwater temperatures, frost-free days, and heavy downpours have all been documented. Global sea level has risen, and there have been large reductions in snow-cover extent, glaciers, and sea ice. These changes and other climatic changes have affected and will continue to affect human health, water supply, agriculture, transportation, energy, coastal areas, and many other sectors of society, with increasingly adverse impacts on the American economy and quality of life.*

Intergovernmental Panel on Climate Change, Contribution of Working Group III to the IPCC Fifth Assessment: *Climate Change 2014: Mitigation: Summary for Policy Makers*, April 2014, http://www.ipcc.ch/

> *Without additional efforts to reduce GHG emissions beyond those in place today, emissions growth is expected to persist driven by growth in global population and economic activities. Baseline scenarios, those without additional mitigation, result in global mean surface temperature increases in 2100 from 3.7 to 4.8°C compared to pre-industrial levels (median values; the range is 2.5°C to 7.8°C when including climate uncertainty, see Table SPM.1).*

American Association for the Advancement of Science (the largest general scientific society in the world and the publisher of the prestigious journal, SCIENCE), *What We Know: The Reality, Risks, and Response to Climate Change*, March 2014 http://whatweknow.aaas.org/wp-content/uploads/2014/03/AAAS-What-We-Know.pdf

> *The overwhelming evidence of human-caused climate change documents both current impacts with significant costs and extraordinary future risks to society and natural systems. The scientific community has convened conferences, published reports, spoken out at forums and proclaimed, through statements by virtually every national scientific academy and relevant major scientific organization — including the AAAS—that climate change puts the well-being of people of all nations at risk.*

U.N. World Meteorological Organization, *WMO Statement on the Status of the Global Climate in 2013*, WMO, March 2014
https://docs.google.com/file/d/0BwdvoC9AeWjUeEV1cnZ6QURVaEE/edit?usp=sharing&pli=1

> *The year 2013 tied with 2007 as the sixth warmest since global records began in 1850. … Thirteen of the fourteen warmest years on record, including 2013, have all occurred in the twenty-first century. … While the rate at which surface air temperatures are rising has slowed in recent years, heat continues to be trapped in the Earth system, mostly as increased ocean heat content. About 93 per cent of the excess heat trapped in the Earth system between 1971 and 2010 was taken up by the ocean. From around 1980 to 2000, the ocean gained about 50 zettajoules (10^{21} joules) of heat. Between 2000 and 2013, it added about three times that amount.*

Intergovernmental Panel on Climate Change, Contribution of Working Group II to the IPCC Fifth Assessment: *Climate Change 2014: Impacts, Adaptation, and Vulnerability: Summary for Policy Makers*, March 2014, http://www.ipcc.ch/

> *Observed impacts of climate change are widespread and consequential. Recent changes in climate have caused impacts on natural and human systems on all continents and across the oceans.*

U.K. Royal Society and U.S. National Academy of Sciences (the two most prestigious science academies in the world), *Climate Change: Evidence and Causes*, February 27, 2014, http://dels.nas.edu/resources/static-assets/exec-office-other/climate-change-full.pdf

> *Earth's lower atmosphere is becoming warmer and moister as a result of human-emitted greenhouse gases. This gives the potential for more energy for storms and certain severe weather events. Consistent with theoretical expectations, heavy rainfall and snowfall events (which increase the risk of flooding) and heat waves are generally becoming more frequent. … While changes in hurricane frequency remain uncertain, basic physical understanding and model results suggest that the strongest hurricanes (when they occur) are likely to become more intense and possibly larger in a warmer, moister atmosphere over the oceans. This is supported by available observational evidence in the North Atlantic.*

Intergovernmental Panel on Climate Change, Contribution of Working Group I to the IPCC Fifth Assessment: *Climate Science 2013: The Physical Science Basis: Summary for Policy Makers*, September 2013, http://www.ipcc.ch/

> *Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased. …It is* extremely likely *that human influence has been the dominant cause of the observed warming since the mid-20th century.* [Emphasis in original. In IPCC terminology, "extremely likely" means the statement's probability of being correct is between 95 and 99 percent.]

Dr. Lonnie G. Thompson (Distinguished University Professor in the School of Earth Science at Ohio State University, winner of the National Medal of Science, member of the U.S. National Academy of Sciences, arguably the most distinguished glaciologist/paleoclimatologist in the world), “Climate Change: The Evidence and Our Options”, Byrd Polar Research Center Publication 1402, 2010 http://researchnews.osu.edu/archive/TBA--LTonly.pdf

> *Climatologists, like other scientists, tend to be a stolid group. We are not given to theatrical rantings about falling skies. Most of us are far more comfortable in our laboratories or gathering data in the field than we are giving interviews to journalists or speaking before Congressional committees. Why then are climatologists speaking out about the dangers of global warming? The answer is that virtually all of us are now convinced that global warming poses a clear and present danger to civilization.*

Dr. Robert McCormick Adams (former Secretary of the Smithsonian Institution) and 254 other members of the U.S. National Academy of Sciences, “Climate Change and the Integrity of Science”, Letters to the Editor, SCIENCE, May 10, 2010
http://www.pacinst.org/wp-content/uploads/sites/21/2013/02/climate_statement3.pdf

> *There is compelling, comprehensive, and consistent objective evidence that humans are changing the climate in ways that threaten our societies and the ecosystems on which we depend. … Natural causes always play a role in changing Earth's climate, but are now being overwhelmed by human-induced changes.*

Dr. Alan Leshner (Executive Director of the American Association for the Advancement of Science) and the Presidents or Executive Directors of 17 other U.S. scientific societies (including the American Chemical Society, the American Geophysical Union, the American Meteorological Society, the American Statistical Association, and the Ecological Society of America), Open Letter to Members of the U.S. Senate, October 21, 2009
http://www.aaas.org/sites/default/files/migrate/uploads/1021climate_letter.pdf

> *Observations throughout the world make it clear that climate change is occurring, and rigorous scientific research demonstrates that the greenhouse gases emitted by human activities are the primary driver. These conclusions are based on multiple independent lines of evidence, and contrary assertions are inconsistent with an objective assessment of the vast body of peer-reviewed science. Moreover, there is strong evidence that ongoing climate change will have broad impacts on society, including the global economy, and on the environment. For the United States, climate change impacts include sea level rise for coastal states, greater threats of extreme weather events, and increased risk of regional water scarcity, urban heat waves, western wildfires, and the disturbance of biological systems throughout the country.*

Dr. Bruce Alberts (President of the U.S. National Academy of Sciences) and the presidents of all of the other national academies of science of the G8+5 countries (which include Russia, China, India, and Brazil), *G8+5 Academies Statement: Climate Change and the Transformation of Energy Technologies for a Low-Carbon Future*, May 2009
http://www.nasonline.org/about-nas/leadership/president/statement-climate-change.pdf

> *Climate change is happening even faster than previously estimated; global CO_2 emissions since 2000 have been higher than even the highest predictions, Arctic sea ice has been melting at rates much faster than predicted, and the rise in the sea level has become more rapid. Feedbacks in the climate system might lead to much more rapid climate changes. The need for urgent action to address climate change is now indisputable.*