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ENERGY INNOVATION AND OTHER POTENTIAL SOLUTIONS TO ADDRESS CLIMATE CHANGE

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Written Testimony of

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Chairwoman Murkowski, Ranking Member Manchin and members of this esteemed committee. Thank you for giving me the opportunity to offer my thoughts on this important topic.

I am a Professor in the Department of Mechanical Engineering at Stanford University and the co-Director of the Stanford Precourt Institute for Energy that coordinates research, education and translation in energy across all of Stanford, the Hoover Institution and SLAC. Between 2009 and 2012, I had the honor to serve as the Founding Director of ARPA-E in the Department of Energy, where I also had the responsibility of the Acting Undersecretary of Energy that involved all the applied energy programs of the DOE. After leaving the DOE, I was briefly the Vice President for Energy at Google. I remain deeply engaged with the energy ecosystem across the world, either through work at Stanford or as a private citizen advising businesses, governments and other organizations. It is with this background that I will offer my perspectives on energy innovation and other potential solutions to address climate change.

Challenges and Opportunities Offered by Climate Change: When we discuss climate change, we often refer to the global average temperature rise of 1.2 ^{o}C since the beginning of the industrial revolution. While this is technically accurate, it misses the larger point: The true impact on human lives is manifested not by the average, but rather by the extreme weather conditions that the rising average produces, such as extreme heat and cold waves, droughts, excessive rain fall and flooding that affect agriculture, livestock, animal and plant diseases, forest fires, air pollution, and the overall health and well-being of Americans across the country. The certainty we now have is that these extremes will occur more often, but the uncertainty is that we can't predict where they will hit next. We are exposed to a game of Russian roulette.

If 1.2 ^{o}C can unleash extreme weather havoc, imagine what 2 ^{o}C would do. To stay below 2^{o}C, the world can emit about 800 billion more tons of carbon dioxide. With a global emission rate of roughly 40 billion tons per year, that would leave just 20 years. Thereafter, the emissions must be zero. In the words of Reverend Martin Luther King Jr, we face the "fierce urgency of now."

It is the moral responsibility of our generation to envision the bright future of a low-carbon economy and hold the beacon of hope to illuminate a pathway that uplifts our people and ensures the security, prosperity and health of all Americans. What can we do?

Technology Innovation via Research and Development: We need affordable solutions to dramatically reduce greenhouse gas emissions from the energy system. Luckily, there is some good news. Today, three game-changing paradigm shifts are shaking up the global energy landscape: unconventional oil and gas revolution due to fracking of shale formations; electrification of transportation via lithium-ion batteries; and carbon-free electricity generation from wind and solar. The rapid cost reduction in these technologies due to R&D have created these tectonic shifts in the energy industry.

Despite this remarkable progress, fossil fuels still comprise 80 percent of global energy use. We have a long way to go. Reducing emissions is a billion-ton-scale problem and it needs billion-ton-scale affordable solutions. What are these potential solutions?

They include: grid-scale storage at one tenth the cost of lithium-ion batteries; small modular nuclear reactors at half the construction cost of today's reactors; refrigeration and air conditioning using refrigerants with no global warming potential; zero net energy buildings at zero net cost; using renewables to produce carbon-free hydrogen at the same cost as that from shale gas; decarbonizing industrial heat needed to make steel, concrete and chemicals and reimagining carbon-neutral construction materials; decarbonizing the food and agriculture sector, and leveraging agriculture to suck out carbon dioxide from the air and store it in the ground; and capturing carbon dioxide from power plant exhausts followed by sequestering it deep underground or using it make plastics or even fuels.

What I am describing is nothing short of a new industrial revolution. This is a remake of much of our economy – electricity, automobiles, steel, concrete, oil, gas, food, agriculture, etc. We stand at the doorstep of a colossal change of the energy sector worth $10 trillion per year, more than 10 percent of the global GDP. This change will impact every human being, and will shape the economy, environment, international security and geopolitics of the 21st century. In short, this global energy transition presents a historic opportunity for every country and region. And the race is on to seize this opportunity. We must ensure that the US remains globally competitive and maintains its technological lead.

To produce new solutions requires R&D based on science and engineering to develop both breakthrough new technologies and rapid improvements in current technologies. I have stated in the recent hearing of the House Science Committee on the Future of ARPA-E that its budget should be increased to $1B, and that we also need to increase the budget and effectiveness of the Applied Energy Programs and that of Basic Energy Sciences to address our nation's opportunities. With the best scientific infrastructure and talent in the world in our Universities and National Laboratories, and with the entrepreneurial spirit that is in the American DNA, the US has a remarkable capacity to innovate and deliver on these investments.

Policy Innovation: Research is necessary but not sufficient. These solutions need to help every American lead a more secure, healthy and prosperous life. For that, we must transition laboratory-scale proof of concept to commercial-scale solutions and an infrastructure to bring those solutions to all Americans. I have two policy recommendations to achieve this.

Low-Carbon Infrastructure Initiative with Federal-State-Private Sector Partnerships: As Justice Brandeis once said: "Our states and local governments act as the laboratories of democracies." The diversity of energy needs that our 50 states offer is our strength because they can become the laboratories of the new low-carbon industrial revolution as well.

In 1936, Congress passed the historic Rural Electrification Act where the federal government provided low-interest loans via local electric power cooperatives to bring electricity services and an enviable quality of life to millions of Americans across our nation. We now need a similar 21st century initiative to develop new and upgraded infrastructure to deliver low-carbon reliable and affordable energy services to all Americans. These include: energy efficient homes and buildings; intelligent electric grid that integrates large amounts of intermittent renewables, storage, as well as zero-emissions nuclear and fossil energy; electrification of public transit, automobiles and rail transport for moving people and freight; low-carbon heat and electrification

of our industry; low-carbon fuels; an agricultural revolution for higher food productivity and negative emissions; and many more.

Such an infrastructure initiative will require partnerships between federal, state and local governments along with the private sector, with the goal to: (a) create an innovation pipeline to use and de-risk new low-carbon technologies; (b) convene joint planning between cities, counties, states and regions to streamline and expedite siting and permitting processes; and (c) create innovative policies that stimulate private-sector financing and public-private partnerships. Low-carbon tax policies such as the Master Limited Partnerships (MLP) Parity Act could enable access to low-cost long-term capital, which is now available only for fossil-fuel infrastructure.

Markets and Regulations: Transition to a low-carbon economy requires either a direct or an indirect price on carbon. I personally prefer the direct approach, and in particular, the proposal by Secretaries Shultz, Baker and many other thoughtful economists: Charge energy producers $40-50 per ton of carbon dioxide emitted, which would incentivize corporations to invest in new low-carbon technologies and raise about $200-250B per year in the US. This could be returned to the people as carbon dividend so that every US citizen would receive a check of $600-700 per year, or $50-60 per month, thus making it progressive. A household could potentially earn about $200 per month. And those that use less energy will come out ahead.

While a price on carbon is effective for the supply side of energy where markets work, there are segments of our energy economy, especially energy efficiency on the demand side, where there are known market failures, ones where prices don't work because of split incentives and a variety of other challenges. What has worked effectively to reduce energy consumption since the 1970s are sensible regulatory measures such as efficiency standards for energy appliances and fuel-efficiency standards for cars and trucks. Buildings need special attention because they consume 40 percent of our primary energy and 75 percent of our electricity. Buildings codes are necessary but they are not sufficient because they focus only on design and do not account for how they are constructed and operated. We need operational performance-based whole building standards to ensure measurable energy efficiency performance.

Education and Training: To design, plan and operate a new low-carbon energy infrastructure, we need a skilled workforce. A few years back I was in a committee of the National Academy of Engineering that produced a report called "Making Value for America." One of the striking findings was that those Americans who did not complete high school found their unemployment rate steadily increase over decades, whereas ones who completed four years of college found their unemployment rate steadily decrease. Therefore, I cannot overemphasize the point that if we are to create the new low-carbon industrial revolution and lead the world, we cannot do so without our people. We must use this opportunity to ensure that our children and grandchildren get the basic education needed to flourish in the 21st century and are not left behind.

Final Comments: While the extreme weather events resulting from climate change pose daunting risks and challenges for all us, it is also an enormous opportunity to bring affordable and reliable low-carbon energy services to all Americans by leveraging our combined innovations in technology, policy and education. In the words of Rev. Martin Luther King Jr., "We are now faced with the fact that tomorrow is today. We are confronted with the fierce

urgency of now. In this unfolding conundrum of life and history, there is such a thing as being too late. This is no time for apathy or complacency. This is a time for vigorous and positive action."