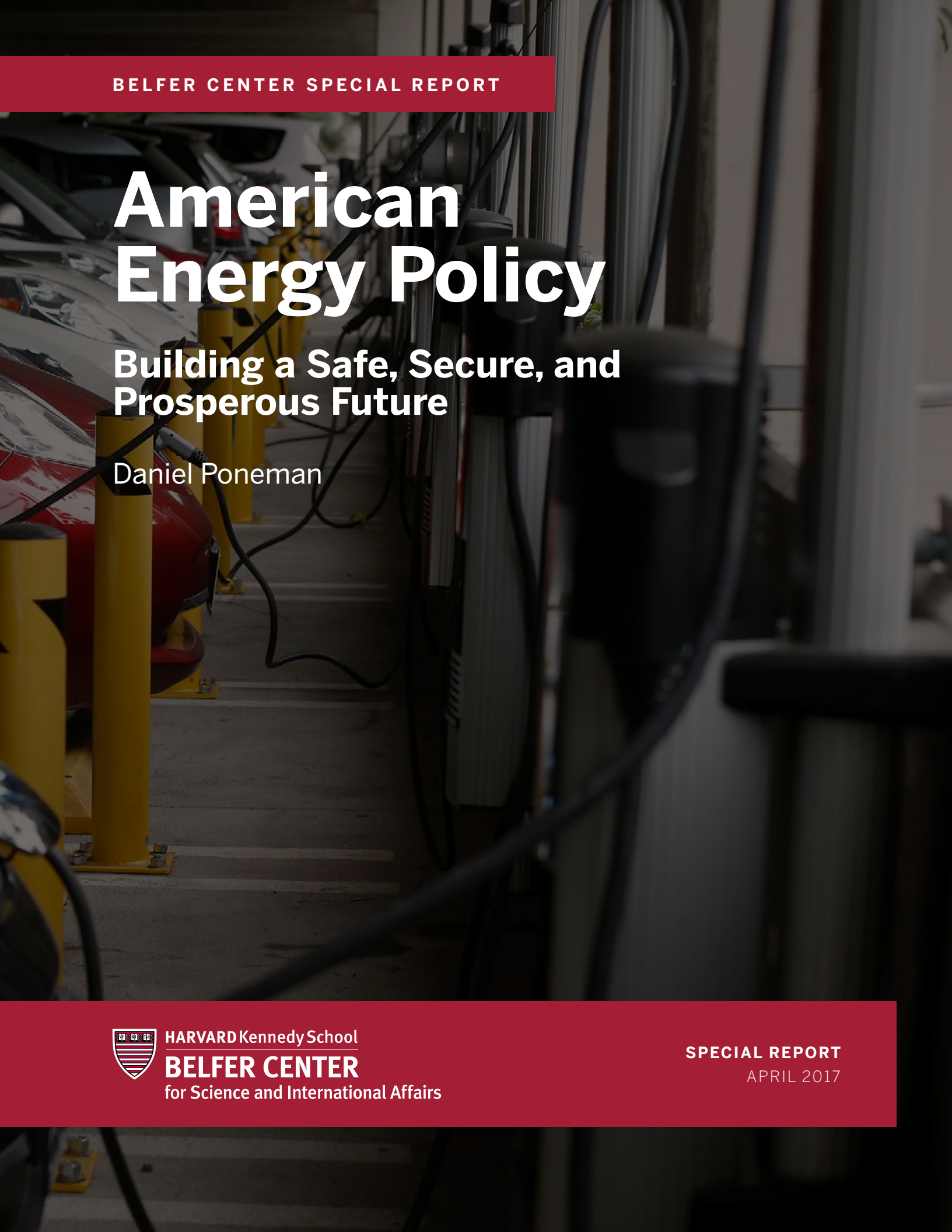

BELFER CENTER SPECIAL REPORT

American Energy Policy

Building a Safe, Secure, and Prosperous Future

Daniel Poneman

HARVARD Kennedy School
BELFER CENTER
for Science and International Affairs

SPECIAL REPORT
APRIL 2017

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Daniel Poneman is the President and Chief Executive Officer of Centrus Energy Corp. (Centrus). Centrus provides enrichment, fuel, and fuel services to utilities that operate nuclear reactors throughout the world and has investments and business interests in some of the sectors discussed in the report. Mr. Poneman wrote this report in his private capacity, and all opinions expressed are his alone. Funding for the report was provided by the Harvard Kennedy School's Belfer Center for Science and International Affairs.

Cover image: Electric cars sit charging in a parking garage at the University of California, Irvine, January 26, 2015. (REUTERS/Lucy Nicholson)

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About the Author

Daniel Poneman is a Senior Fellow with the Belfer Center. From 2009-2014, Poneman was Deputy Secretary and Chief Operating Officer of the Department of Energy. Between April and May 2013, he was Acting Secretary of Energy.

Poneman's responsibilities at the Department spanned the full range of energy issues, including fossil and nuclear energy, renewables and energy efficiency, and international cooperation around the world. He led the 2009 negotiations to address Iran's nuclear program and played an instrumental role in the Department's response to crises from Fukushima to the Libyan civil war to Hurricane Sandy. He also led the Department's efforts to strengthen emergency response and cybersecurity across the energy sector.

From 1993 through 1996, Poneman served as Special Assistant to the President and Senior Director for Nonproliferation and Export Controls at the National Security Council.

Poneman has published widely on energy and national security matters and is the author of *Nuclear Power in the Developing World* and *Argentina: Democracy on Trial*. His book *Going Critical: The First North Korean Nuclear Crisis* (coauthored by Joel Wit and Robert Gallucci), received the 2005 Douglas Dillon Award for Distinguished Writing on American Diplomacy.

Note: Daniel Poneman is the President and Chief Executive Officer of Centrus Energy Corp. (Centrus). Centrus provides enrichment, fuel, and fuel services to utilities that operate nuclear reactors throughout the world and has investments and business interests in some of the sectors discussed in the report. Mr. Poneman wrote this report in his private capacity, and all opinions expressed are his alone. Funding for the report was provided by the Harvard Kennedy School's Belfer Center for Science and International Affairs.

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This project would have never happened but for Graham Allison's invitation to return to the Belfer Center for Science and International Affairs as a nonresident fellow, after a brief thirty-year hiatus. I am sincerely grateful to him for offering me that opportunity. In all important respects the Belfer Center had not changed; it remains a place electric with ideas and imbued with the excitement of people of all ages and points of view working hard to solve the world's toughest and most important problems. And the colleagues and wonderful staff there—including Sarah Donahue, Patty Walsh, Isabel Carey, and Andrea Duarte—have been generous and supportive in every way.

Graham Allison not only encouraged me to undertake this project but provided guidance and support throughout the project. Executive Director for Research and my former government colleague Gary Samore provided over-all guidance and direction in the project, identified lacunae to address, and shared his own perspectives on the issues addressed in the report. Roger Sant, David Sanger and Will Tobey generously and repeatedly provided advice and counsel, as well as detailed comments.

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Table of Contents

Electric cars sit charging in a parking garage at the University of California, Irvine, January 26, 2015.

REUTERS/Lucy Nicholson

Introduction: **An Energy Policy for the Future**

In August 2016, my Belfer Center report, *American Nuclear Diplomacy*, argued that we face two existential threats of human origin: nuclear annihilation and catastrophic climate change.

American Nuclear Diplomacy urged that we fight both threats aggressively, including through accelerating the deployment of all low-carbon sources of energy, including nuclear power. It further argued that the right kind of practices and policies can manage the inherent risks of nuclear technology being diverted to hostile nations or terrorists so that, on balance, we can embrace nuclear energy as part of our long-term strategy to hedge against the risk of catastrophic climate change.

This report assumes that the nonproliferation policies and approaches advocated in *American Nuclear Diplomacy* are accepted and implemented, then asks what *other* policies and approaches must be adopted so that American energy policy can form a strategically consistent whole, driving economic growth while protecting our environment? It will again focus significantly on nuclear energy, as that is the source where the most work still needs to be done to unlock its full potential.

In formulating American energy policy, we should start from first principles. Energy has always been and will continue to be the fountainhead of our prosperity. Until the mid-1800s, wood was the United States' primary energy source. Coal then fueled the Industrial Revolution and remained our predominant domestic energy source until replaced by petroleum products midway through the twentieth century, when natural gas use also came to the fore.

As American energy use grew, so did the U.S. economy, surging from just 1.8 percent of world gross domestic product in 1820 (lagging behind the economies of China, Europe, Japan, and India) to nearly 19 percent by 2008, thus becoming the largest economy in the world. As the country was endowed with

plentiful coal, oil, and natural gas deposits, its economy was spurred on by cheap energy, and users did not feel strong reasons to conserve.

All that has changed. We now realize that our seemingly abundant resources are in fact limited, their development is costly, their overuse robs profits from the bottom line, and in some cases their use seriously damages our health and environment.

This report advocates a set of policies to put U.S. energy policies on track to strengthen our economy while protecting our environment. Part I urges that we impose a price on carbon emissions, and that we align incentives to promote energy efficiency and increased use of clean energy, while leveling the playing field among *all* forms of lower-carbon-emitting energy sources. It calls for increased public and private investment in basic science and technology in order to stimulate greater innovation in the energy sector. And it recommends converting the hortatory goals of the 2015 Paris Agreement on Climate Change into practical implementation.

Part II of this report calls for a significant acceleration in the deployment of nuclear energy. The Paris Agreement pledged parties to limit the earth's warming in the twenty-first century to well below 2˚C and "to pursue efforts to limit the temperature increase even further" to 1.5˚C. But even if all nations fulfilled 100 percent of their commitments in support of the Paris Agreement, experts agree that the world would still miss the 2˚C goal by at least 2˚C, or perhaps by as much as 5˚C. And these existing pledges already include ambitious targets for the ramping up of renewables, gains in energy efficiency, and other carbon-limiting approaches.

The upshot: the world needs to maximize *all* low-carbon sources of energy.

That means we will need a lot more nuclear power. For nuclear energy to fill this role successfully, several long-standing challenges must be successfully addressed.

First, a deep-seated safety culture must infuse the industry from top to bottom across the globe; one more accident on the scale of Fukushima would likely bring the future of nuclear energy to a screeching halt.

Second, the United States must stop kicking the can down the road and implement a sensible, community-based solution to nuclear waste, following the path charted by countries like Finland.

Third, nuclear energy must be compensated for generating carbon-free power and providing base-load reliability at a time of cheap natural gas, sluggish electricity demand, no price on carbon emissions, and deregulated power markets that nevertheless contain government incentives benefiting nonnuclear energy sources.

Finally, nuclear energy cannot flourish without addressing the fundamental security concerns that occupy much of *American Nuclear Diplomacy*: combating the inherent risk that nuclear materials and technology will be diverted from peaceful to evil uses. So this report will echo the call from its companion report for the establishment of an assured nuclear fuel services initiative, along with other steps to reduce the potential dangers posed by large-scale reliance on nuclear energy.[1]

No set of American energy policies can succeed if they are not widely accepted and consistently implemented over many decades. If we go back and forth between on-again, off-again tax credits, promulgated and repealed laws and regulations, and other twists and turns in the rules of the road on the legal and economic framework governing energy and the environment, then our Nation we will inevitably fail to serve its citizens and fulfill their long-term aspirations. Investments in energy often take many years to realize adequate return to their investors, power generation assets may operate for many decades, and if there is no confidence in the stability of the investment environment for energy—whether power generation and clean vehicles, or efficient homes and office buildings—then investors will simply look for other ways to deploy their capital.

On the other hand, if Americans can join together to support a set of energy policies like those proposed in this report, and stick to it, then we will be able to have our cake and eat it, too—saving money, cleaning the environment, creating jobs, strengthening our national security, and enhancing our global leadership.

1 For additional thoughts on proliferation-resistance and steps to increase it, see https://www.belfercenter.org/sites/default/files/files/publication/prolif-resist-talk-2014.pdf

And here is the kicker: *we can agree on what to do even if we do not agree on why.* I have made it clear in this and my earlier Belfer report that I believe that climate change poses an existential threat to humanity and must be urgently addressed. That view may not be embraced by the new presidential administration or by key leaders in the US Congress. That said, every recommendation in this report could command bipartisan support even in today's contentious political environment if people turned away from divisive politics and focused instead on the things they cared most about—be it promoting American jobs and manufacturing, strengthening our global leadership, increasing our national security and, yes, cutting carbon emissions.

If we embrace these ten recommendations, we can build an American energy policy for the future—at once advancing our energy, environmental, economic, and security goals.

Finally, a personal note: some may wonder whether my advocacy for a more vigorous approach to nuclear energy in the United States is influenced by my current employment by a nuclear fuel company. To the contrary: for better or worse my views on the role of nuclear energy have remained consistent since I first worked on this subject as a summer intern in 1975 and 1976 for the late Senator John Glenn, a true American hero, who first inspired my passion to work on combatting the spread of nuclear weapons. For over forty years I have been consumed by the challenge of trying to solve the equation of how to unlock the peaceful potential of the atom without unleashing its terrors. And as the pages that follow will show, I continue to believe strongly that we will need to tap all available energy sources to serve the expanding needs of a growing global population, even as we seek to decarbonize our energy systems—including the fossil fuels that are destined to remain part of our energy mix in the coming decades. It is just that, among these sources, nuclear energy will require more policy steps to unlock its full potential—and mitigate its unique risks. Thus the need for Part II of this report.

Part I:
Rising to the Challenge

Historically, when Americans have faced great challenges, they have taken up the gauntlet and prevailed. The magnitude of the challenge does not paralyze, deter, or discourage efforts to tackle it; rather, it inspires determination and innovation.

Within the span of living memory, the United States mobilized its massive industrial base to join our allies in defeating the Axis powers in World War II. It led the creation of an Atlantic alliance whose multifaceted strategy persistently confronted the threat of Soviet expansion and domination. It helped rebuild the shattered post-war economies of Western Europe through the Marshall Plan, which for four years consumed 10 percent of the federal budget and over 2 percent of the U.S. gross national product (GNP). The country further invested in maintaining a massive conventional force in Western Europe, backed up by a robust nuclear arsenal. And it participated in a comprehensive export-control regime known as the Coordinating Committee on East-West Trade, or COCOM—a policy of sustained commercial restraint that the world has seldom seen—in order to protect allied military superiority during the Cold War.

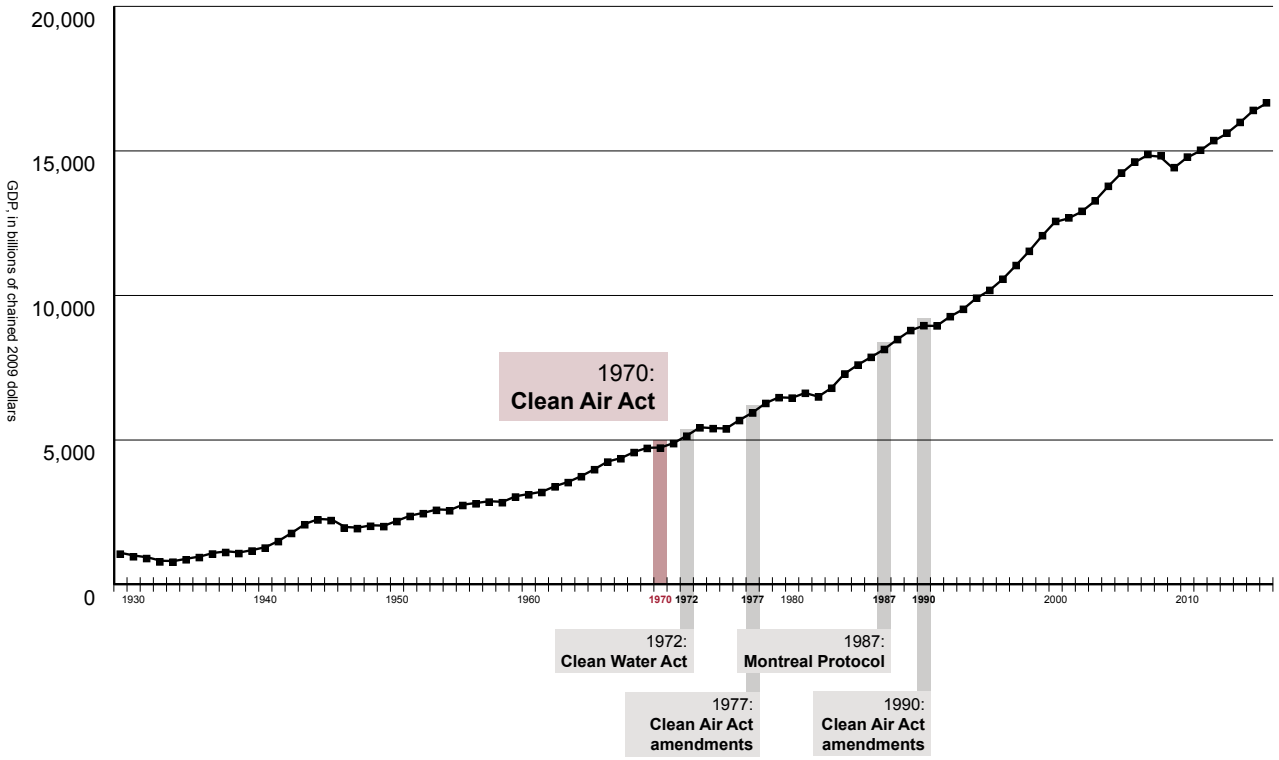
This can-do spirit has also supported U.S. efforts to protect public health, including through environmental protection. In the 1960s, many worried that tackling air pollution though strong legislation would drive up energy costs and scarcity, and drive down American prosperity. But public concern about air pollution grew so strong that the Clean Air Act of 1970 passed the Congress overwhelmingly. The law initially regulated four major classes of pollutants—particulate matter, sulfur dioxide, carbon monoxide, and volatile organic compounds—with market incentives playing an important role.[2]

In 1990 Congress passed tighter emission controls, expanding their scope to include nitrogen oxide and smaller particulate matter. Congress also expanded market incentives, such as permitting the purchase and sale of emissions allowances. Polluters unwilling to make the additional capital investment to reduce emissions could instead buy allowances from companies that had succeeded in driving down their emissions. And it worked. By 2012, emissions

2 Roger Sant, "Solving the Carbon Problem Together," Sant Foundation, March 2015, 22–23. http://santfoundation.org/wp-content/uploads/2015/03/RWS-SlideDoc-032015.pdf.

of all six pollutants had dropped 60–80 percent, while the U.S. economy had grown 3.5 times.[3]

U.S. GDP and the Clean Air Act



In the 1980s, Secretary of State George P. Shultz faced the same kind of debate. Scientists were warning that increasing concentration in the earth's atmosphere of chlorofluorocarbons (CFCs)—widely used in refrigeration, foam insulation, industrial solvents, and aerosol propellants—was threatening the world's ozone layer. Thinner ozone would provide less protection against Ultraviolet B radiation reaching the earth's surface, which could substantially raise skin cancer risks. Satellite imagery confirmed this dangerous thinning over Antarctica, giving rise to popular concern over the "hole in the ozone."

While environmentalists called for urgent action, the CFC industry discounted the scientific evidence of ozone depletion, and economists warned of dire economic consequences from measures curtailing CFC emissions. In the face of this conflicting evidence, Shultz said, "Since we know that the consequences are severe, we'll take out an insurance policy."[4] He therefore instructed

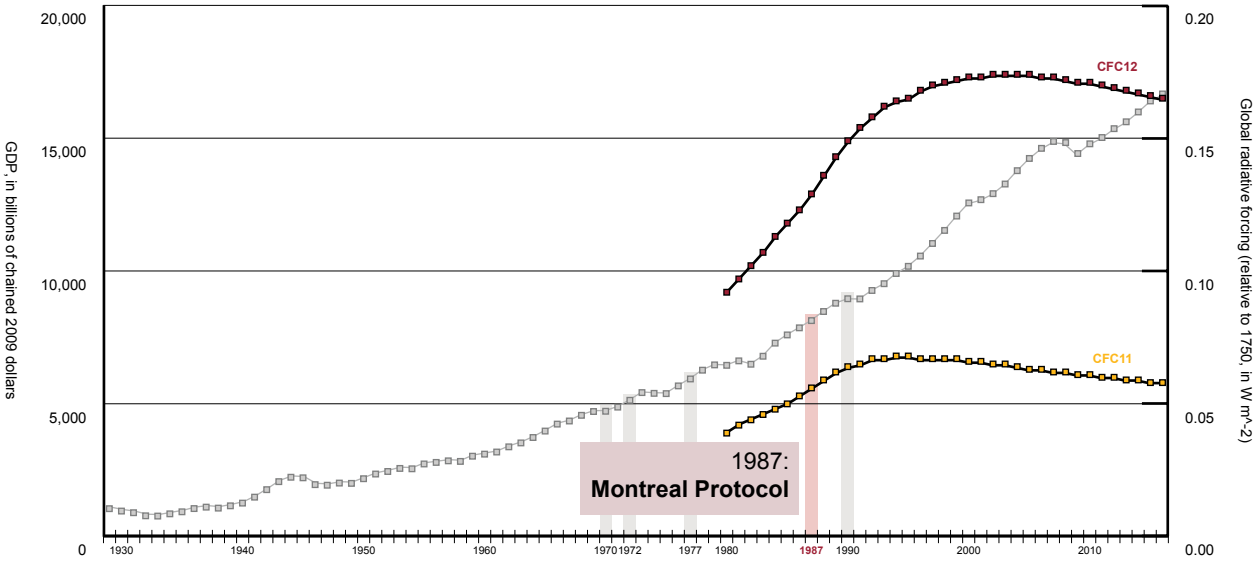
3 Ibid.

4 Dan Morain, "Take It from George Shultz, Everyone Needs a Little Insurance," *Sacramento Bee*, June 24, 2015, http://www.sacbee.com/opinion/opn-columns-blogs/dan-morain/article25444039.html.

State Department negotiators to explore a multilateral agreement to curtail emissions of CFCs. That simple, common-sense decision led the United States to play a leadership role in the multilateral negotiations for the 1985 Vienna Convention for the Protection of the Ozone Layer. By 1987 negotiators concluded the Montreal Protocol, which mandated phasing out of several classes of CFCs. Despite resistance from auto companies, appliance manufacturers, and the military, the U.S. Senate ratified the protocol unanimously.

The Montreal Protocol has proved to be an enormous success and now boasts 197 parties. As of 2005, they had phased out the consumption of over 95 percent of the chemicals controlled by the Protocol, with consumption in developed countries plummeting 99 percent. Conservative estimates released in 2015 by the United Nations Environment Program indicate that the United States will have avoided over two million skin cancer cases per year by 2030. Moreover, approximately 100 to 150 million skin cancer cases, along with tens of millions of cataract cases, will be avoided worldwide by 2100. These and other positive health outcomes, along with agricultural and productivity benefits associated with the Protocol, are estimated to result in $1.8 trillion in global economic gains.[5]

U.S. GDP, CFC Levels, and the Montreal Protocol



5 United Nations Environment Programme, *The Montreal Protocol and Human Health*, 2015. This progress does not justify complacency. Even with the successful efforts of the past 30 years, the ozone hole is not expected to return to pre-1980 levels until between 2060 and 2075.

Beyond its health and environmental benefits, the Montreal Protocol also spurred innovation, improved efficiency, and created new industries. It has driven up to 60 percent efficiency savings in some air-conditioning and refrigeration sectors as older equipment has been replaced with more efficient machines. This progress, coupled with decreased maintenance costs and improved reliability and safety standards, has resulted in savings of close to 7 billion kilowatt hours per year and close to $500 million annually.[6]

Twenty years later, George Shultz applied lessons from this experience to the current challenge of climate change. The success of the Montreal Protocol, he maintained, reflected strong American leadership from the scientific community and the president of the United States. It also showed the importance of achieving universal coverage, involving the relevant constituencies, and applying economic incentives. In 2007, the accelerating loss of the Arctic summer sea ice and the alarming ice losses in Greenland led him to renew his plea:

> We all know there are those who have doubts about the problems presented by climate change. But if these doubters are wrong, the evidence is clear that the consequences, while varied, will be mostly bad, some catastrophic. So why don't we follow Reagan's example and take out an insurance policy?[7]

Recognizing the success of the Montreal Protocol, the international community replicated it in an October 2016 meeting in Kigali, Rwanda. There representatives from over 170 nations agreed to amend the Protocol by capping and then significantly reducing the emission of hydrofluorocarbons (HFCs), which were widely adopted as substitutes for CFCs pursuant to the Montreal Protocol. While HFCs do not damage the ozone, pound for pound they contribute to global warming more than CO_2, and the Kigali Amendment to the Montreal Protocol is projected to cut the equivalent of roughly 70 billion tons of carbon dioxide from the atmosphere, or around two years' worth of global carbon emissions. And, unlike the Paris Climate Agreement, the Kigali Amendment is legally binding. Secretary of State Kerry welcomed the accord, noting that its implementation could cut global warming by ½°C this century.[8]

6 Rebecca Lefton with Ben Bovarnick, "Top 5 Reasons to Phase Down HFCs in the Montreal Protocol," Center for American Progress, October 23, 2013.

7 George P. Shultz, "How to Gain a Climate Consensus," *Washington Post,* September 5, 2007,.http://www.washingtonpost.com/wp-dyn/content/article/2007/09/04/AR2007090401759.html.

8 John Kerry, "An Ambitious HFC Amendment to the Montreal Protocol," U.S. Department of State, October 15, 2016, https://www.state.gov/secretary/remarks/2016/10/263170.htm.

A clear pattern emerges from these experiences. When the country faces a major threat, a dedicated minority recognizes it and lobbies hard for strong actions to address it. Stakeholders with powerful vested interests in the status quo lobby just as hard (sometimes harder) to block the proposed actions. In many cases, the advocates for change never get past this stage.

Given sufficient leadership and popular support, however, in some cases effective measures have been adopted, tremendous benefits achieved, *and the dire warnings of economic damage from these measures have turned out to be wrong.* Instead, the environmental initiatives succeeded in strengthening the environment *while* the economy grew.[9]

When faced by an imperative to reduce pollutants, companies have invested in technology and innovation and found that in driving down pollutants they also drove down costs. This result has occurred many times. In response to the 1970s energy crisis, for example, California introduced the first-ever efficiency standards for refrigerators in 1976. By 2009, the average new U.S. refrigerator used 72 percent less electricity than the corresponding 1976 model, but performed better and cost 65 percent less.[10]

What can we learn from these past successes in facing global threats?

9 There are many parallels between the Montreal negotiations and the climate negotiations that led to the Paris Climate Agreement besides serving as drivers for innovation. For example, the chief U.S. negotiator for the Protocol, Robert Reinstein, noted the need to grant leeway to developing countries that had contributed less to the problem and were less morally responsible as well as economically capable to respond. So Article 5 of the Protocol gave developing countries a ten-year grace period to comply with the Protocol, unless their per capita use of the chemicals hit a point that would trigger the same control limits as industrialized countries.

10 Marianne DiMascio, "How Your Refrigerator Has Kept Its Cool Over 40 Years of Efficiency Improvements," ACEE, September 11, 2014; http://aceee.org/blog/2014/09/how-your-refrigerator-has-kept-its-co

1. Bending the carbon curve: the value in hedging

Once again we face the prospects of environmental disaster, but on a greater scale than ever before. And as always, understandable concerns about the economic burden of taking action have led many to challenge the science and resist strong remedial action. But even if the science were ambiguous, even if there were only a small chance of provoking catastrophic climate change, wouldn't it make sense to take out an insurance policy to hedge against that risk? Isn't that how people typically manage low-probability, high-consequence events, on the theory that a relatively modest investment now can at least partially offset potentially enormous damages if that event actually occurs?

The view that we should hedge against the risk of catastrophic climate change has been gaining ground. Former Treasury Secretary Henry Paulson drew an analogy between climate change and the 2008 financial crisis:

> The nature of a crisis is its unpredictability. And as we all witnessed during the financial crisis, a chain reaction of cascading failures ensued from one intertwined part of the system to the next. It's easy to see a single part in motion. It's not so easy to calculate the resulting domino effect. That sort of contagion nearly took down the global financial system.
>
> With that experience indelibly affecting my perspective, viewing climate change in terms of risk assessment and risk management makes clear to me that taking a cautiously conservative stance—that is, waiting for more information before acting—is actually taking a very radical risk. We'll never know enough to resolve all of the uncertainties. But we know enough to recognize that we must act now. [11]

Action to hedge against the risk could come from three sources: voluntary action, government mandates, or a combination of the two, i.e. public policy that sets up incentives to help shape, but not compel, private action.

11 Henry M. Paulson, Jr., "The Coming Climate Crash," *New York Times,* June 21, 2014, http://www.nytimes.com/2014/06/22/opinion/sunday/lessons-for-climate-change-in-the-2008-recession.html?_r=0.

Voluntary action is already widely practiced, from homeowners installing solar panels and gardeners raising their own food through sustainable methods, to CEOs investing in energy efficiency to lower production costs and improve productivity. Absent a stronger price signal than now exists in the marketplace, however, neither virtuous intent or self-interest are likely to be strong enough to drive significant investments to cut carbon emissions. Therefore, voluntary action can make a useful contribution but is unlikely to suffice to meet the size of the climate challenge.

Government mandates to cut carbon emissions can work, but they can also be complex and controversial. At best, as in the case of the refrigerator regulations, they end up producing a triple win of higher corporate profits, greater consumer satisfaction (from both lower prices and better performance), and cleaner air. Another successful regulation was fuel efficiency in vehicles. In 2011, following a negotiation involving automakers, unions, environmental advocates, federal agencies, and the states, fuel efficiency standards were doubled, to 54.5 miles per gallon by 2025. And in 2014 the president directed the Environmental Protection Agency (EPA) and the Department of Transportation to set the next round of fuel efficiency standards for medium- and heavy-duty vehicles, based on the same logic and approach:

> Improving gas mileage for these trucks [is] going to drive down our oil imports even further. That reduces carbon pollution even more, cuts down on businesses' fuel costs, which should pay off in lower prices for consumers. So it's not just a win-win, it's a win-win-win.[12]

Of course, government mandates often run into fierce resistance from those subjected to their burdens, which contributed to the failure of comprehensive climate legislation in the U.S. Congress. Frustrated by the lack of effective legislative action on climate change, President Obama increasingly exercised presidential authority, saying that "we can't wait for an increasingly dysfunctional Congress to do its job. Where they won't act, I will."[13] He directed the EPA to impose a Clean Power Plan, which set carbon dioxide (CO_2) emissions performance targets for states that reflect the "best system of emission

12 The White House, "Remarks by the President on Fuel Efficiency Standards of Medium and Heavy-Duty Vehicles," February 18, 2014. https://obamawhitehouse.archives.gov/the-press-office/2014/02/18/remarks-president-fuel-efficiency-standards-medium-and-heavy-duty-vehicl

13 Barack Obama, "We Can't Wait," The White House, October 24, 2011, https://obamawhitehouse.archives.gov/the-press-office/2011/10/29/weekly-address-we-cant-wait-strengthen-economy-and-create-jobs

reduction," but left it up to the states to develop their own plans to achieve those reductions.[14]

Not surprisingly, many parties objected, including twenty-seven states, coal producers, electrical utilities, and business groups. They sued the EPA to block the plan's implementation, arguing that the EPA had exceeded its authority under the Clean Air Act and expressing concerns about the economic feasibility of the plan. More surprisingly, the Supreme Court intervened, staying implementation of the plan pending the outcome of the opponents' legal challenges in the lower Court of Appeals, the first time the Supreme Court had ever stayed a regulation before a single court had adjudicated it. The ruling blocked the implementation of the plan for the rest of the Obama administration and—given the results of the 2016 presidential election—perhaps forever.

The third approach to hedging risks is to use law and policy to influence, but not compel, private conduct. The simplest way to do that would be to put a price on carbon emissions because that (a) would target precisely the element we are seeking to control without the intervention of market-altering measures in the tax code or other regulations, and (b) would rely upon the most efficient allocator of resources: the free market.

Using a market-oriented approach to cutting CO_2 emissions makes sense because American prosperity has depended on the power of free markets to leverage the forces of supply and demand to drive resources to their highest and best use in society. For markets to perform that function efficiently and fairly, however, they need to bring all "external" elements—i.e. benefits or burdens that affect society (including market participants) but that are not accounted for within the marketplace—inside the system of resource allocation that markets control.

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14 The "building blocks" the states could use to meet their targets included shifting power generation to zero-carbon emitters such as new nuclear power and renewable energy generators, or to natural gas-fired plants, which emit only half as much CO_2 per million British thermal units (MBtu) compared to coal. They also included the option of improving the efficiency of coal-fired plants–either running them at higher temperatures, or reducing the conversion losses as the coal-fired steam drives turbines to generate electricity. Those measures do not reduce CO_2 emissions directly but, by improving coal-plant efficiencies, they reduce the amount of coal that needs to be burned and drives down emissions that way.

In order to provide time to adjust, the EPA did not require immediate achievement of the states' targets, but provided a glide-path for implementation of the performance rates, which were to be phased in from 2022 (the first year that reductions would be mandatory) to 2029.

Carbon emissions are just such an external element. Those who emit carbon benefit from the revenues generated by their economic activities, but they do not pay to clean the air that they pollute or reimburse the medical bills of those whose health is damaged or destroyed by air pollution. They don't restore power and homes to families who suffer from more intense hurricanes driven by climate change, or compensate businesses whose factories or commercial properties are damaged or destroyed.

Indeed, not only are carbon emitters getting a free ride in most markets, they are actually subsidized. The International Energy Agency (IEA) has found that tax breaks, subsidized fossil fuel prices, and other government supports generate an incentive to pollute worth $115 per metric ton of carbon dioxide. Meanwhile, efforts to burden carbon emissions by requiring, essentially, "permits to pollute," have priced carbon at $7 per metric ton, resulting in a net subsidy of $108 per metric ton.[15] While fossil fuel subsidies range widely—from $29 per metric ton in China to $173 per metric ton in the Middle East—in all regions the subsidies far exceed the burden placed on carbon emissions.[16] So despite all the concerns about climate change and the highly mature nature of the oil and gas industries—factors that would all seem to militate for eliminating fossil fuel subsidies—tax, regulatory, and policy approaches *encourage* CO_2 emissions far more than they discourage them.

When challenged on the wisdom of maintaining these fossil fuel subsidies—which drain public treasuries and stimulate CO_2 emissions—officials often reply that fuel subsidies are a form of social welfare and that their repeal would be regressive, raising fuel prices on those least able to afford it. According to IEA Director General Fatih Birol, the premise of that concern "is completely wrong.... What we found out," he continued, "was that of this $500 billion subsidy, only eight percent of this money goes to the lowest 20 percent income groups. More than 90 percent of this money goes to medium-and-high income groups".[17]

15 International Energy Agency, *Energy and Climate Change*, 2015, https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf.

16 In North America, carbon prices and subsidies each cover about 4 percent of emissions, according to the IEA. The subsidies amount to $36 a ton on average, while the carbon price is $9 a ton. Latin American subsidies are $208 a ton, compared with $173 a ton in the Middle East, $168 in Africa, $104 in India, and $29 in China.

17 Matthew Carr, "Subsidies at 16 Times Carbon Prices Stymie Pollution Curbs," *Bloomberg*, June 14, 2015, http://www.bloomberg.com/news/articles/2015-06-14/fuel-subsidies-at-16-times-carbon-prices-stymie-pollution-curbs.

What to do? It is time to move beyond analysis and argument to concrete actions—ten steps that, if implemented, would put the United States and the world on a path to a secure and prosperous future. The first recommendation is the simplest to express, potentially the most powerful in its effect, and the most uncertain in its political fate.

Recommendation 1: **Put a price on carbon emissions.**

If we want to harness the power of American innovation to drive down carbon without damaging our economy, the cleanest, clearest, most direct way to do that is to put a burden on carbon emissions. Consider the following logic:

> The U.S., with its market-based economy, will find it difficult if not impossible to substantially further decrease its GHG [greenhouse gas] emissions without introducing higher costs or regulatory controls associated with GHG emissions from development, delivery, or combustion of fossil fuels. Absent a price on carbon, energy efficiency and those power sources with lower carbon intensity—such as renewables, nuclear, and natural gas—will tend to be undervalued as individuals, businesses, and governments make decisions. A price on carbon emissions, implied or explicit, or similar regulatory action that prices the environmental costs of fossil fuel emissions, will help to accelerate shifts to lower carbon-intensity sources of electric power. Such policies could take the form of an explicit carbon price, such as a carbon tax, or other market mechanisms.

That finding comes not from an impassioned environmentalist or ivory-tower academic, but from the National Petroleum Council, in a 2011 report that was endorsed by the leaders of most of America's major oil companies, known more for bottom-line pragmatism than dewy-eyed sentimentalism.[18]

The notion that putting a price on carbon emissions is philosophically conservative, not liberal, was shared by former Treasury Secretary Paulson, who wrote in *The New York Times*:

18 National Petroleum Council, *The Prudent Development of North American Oil and Gas Resources,* 2011. http://www.npc.org/nard-execsummvol.pdf. Carbon intensity measures the amount of carbon by weight emitted per unit of energy consumed.

> The solution can be a fundamentally conservative one that will empower the marketplace to find the most efficient response. We can do this by putting a price on emissions of carbon dioxide—a carbon tax.[19]

Failing to penalize carbon emissions robs society of its most powerful, efficient tool in combating climate change. Furthermore, as columnist Tom Friedman observed, "my gut tells me that if the U.S. government puts a price on carbon emissions, even a weak one, it will usher in a new mind-set among consumers, investors, farmers, innovators, and entrepreneurs that in time will make a big difference—much like the first warnings that cigarettes could cause cancer. The morning after that warning no one ever looked at smoking the same again."

Can such a simple yet dramatic step be legislated in today's political environment? Recent history is not encouraging. The country has become more polarized and less capable of passing major legislation than perhaps at any time in its history. The last serious effort to enact comprehensive climate legislation, during President Obama's first term, showed how a cumbersome process could sink the effort. U.S. Representatives Henry Waxman (D-CA) and Ed Markey (D-MA) sponsored the American Clean Energy and Security Act, which, instead of instituting a simple carbon emissions tax, opted for a "cap and trade" approach. This would have established a mandatory cap on greenhouse gas emissions and a market-based permit trading system, including the use of agricultural and other offsets, to achieve the schedule of 83 percent reduction in GHGs through 2050. Advocates of cap-and-trade favored its use of market-related incentives.[20] Critics objected that cap-and-trade systems invite complexity (in allocating ceilings on GHG emissions among different industries) and politically-influenced caps that distort allocation of

19 Henry M. Paulson, Jr., "The Coming Climate Crash," *New York Times*, June 21, 2014, http://www.nytimes.com/2014/06/22/opinion/sunday/lessons-for-climate-change-in-the-2008-recession.html?_r=0.

20 As Nobel Prize-winning economist Paul Krugman explained, "Even when polluters get free permits, they still have an incentive to reduce their emissions, so that they can sell their excess permits to someone else. That's not just theory: allowances for sulfur dioxide emissions are allocated to electric utilities free of charge, yet the cap-and-trade system for SO_2 has been highly successful at controlling acid rain." In "The Perfect, the Good, the Planet," *The New York Times,* May 17, 2009, http://www.nytimes.com/2009/05/18/opinion/18krugman.html

resources, while bringing windfalls to industries in transition through overly generous allocations of pollution credits.[21]

The complexity of the subject matter was perhaps matched by the complexity of the legislative process itself. Extensive puts and takes were proposed by the many stakeholders in the energy and climate arena.[22] The *Washington Post* described the bill as "swollen with loopholes and giveaways meant to win over un-green industries and wary legislators."[23]

On June 26, 2009, this legislative behemoth squeaked by with a narrow 219–212 majority in the House of Representatives. Attention then turned to the Senate, where Senators John Kerry (D-MA), Joe Lieberman (I-CT), and Lindsay Graham (R-SC) worked for eight months on companion legislation to Waxman-Markey, engaging yet again with a panoply of environmentalists, academics, industry representatives, and others, with a view to producing a bill that could pass the Senate, reconcile with the House bill, and wind up on the President's desk for signature. Senators Kerry and Lieberman (Graham declined to join in the end) introduced this slightly less hefty bill in May 2010, but it lacked sufficient support to pass the Senate, and in July 2010 Senate Majority Leader Harry Reid (D-NV) announced he would not bring it forward for a vote.[24]

Six years later, as evidence mounts regarding the clear and present dangers of climate change, it may be time to revisit the possibility of legislation.

Why should the effort fare any better this time, especially with a White House and both houses of Congress controlled by a Republican Party skeptical of the need for dramatic action to fight climate change?

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21 Waxman-Markey included a number of additional provisions aimed at reducing greenhouse gas emissions. A Renewable Electricity Standard would have required utilities to meet 20 percent of their 2020 power needs from renewable energy sources or energy efficiency. New coal-fired power plants would need to cut CO_2 emissions by 50 percent compared to existing plants, a number that would rise to 65 percent for plants licensed after 2020. The bill also promoted more energy-efficient building standards, carbon capture and sequestration technologies that would reduce emissions from coal-fired power plants, and clean-energy financing mechanisms that would benefit low-carbon emitters, including nuclear.

22 For example, to build stakeholder support for the bill, the sponsors bargained away free emissions allowances for a ten- to twenty-year transition period. Initially, the federal government would have auctioned off only 15 percent of the emissions allowances to raise revenue, while the rest would have gone to local electricity distributors, carbon-intensive industries, state governments, and others.

23 Ibid.

24 Coral Davenport and Darren Samuelsohn, "Dems Pull Plug on Climate Bill," *Politico*, July 22, 2010, http://www.politico.com/story/2010/07/dems-pull-plug-on-climate-bill-040109.

First, there is a growing acceptance of the need for action, including from a politically conservative vantage. In February 2017, former Secretary of State James A. Baker III added his voice to the chorus of eminent Republican leaders to support a climate tax, joining former Secretary of State George Shultz in proposing a four-pillared plan, including a gradually increasing carbon tax (starting at $40-per-ton), a "carbon dividend" payment that would distribute the revenues raised by the carbon tax to the American people, a border adjustment that would rebate carbon tax payments to U.S. companies when they export to countries without comparable carbon pricing systems, and finally the elimination of regulations that would no longer be necessary after enactment of the carbon tax.[25]

Second, if a pragmatic coalition of business interests and environmental organizations could find sufficient common ground, then having the White House and the Congress all controlled by the Republican Party could increase the odds of passing legislation. (This perspective evokes the classic view that only a renowned hardline anti-Communist such as Richard Nixon could open up diplomatic relations with Communist China without being outflanked by political opponents.)

In addition, the surest way to get out from under overly-burdensome administrative regulations would be to pass comprehensive legislation superseding proposed EPA regulations like the Clean Power Plan. Legislation aimed at cutting air pollution and carbon emissions could also include other business-friendly provisions (more on that later) to secure support from a wide array of environmental and business organizations. The new Republican majority may be attracted to showing that under their leadership Washington can start working again.

So logic and experience bring us back to the simplest and most direct approach to cutting carbon emissions: a carbon emissions tax. It is easier to understand and administer, and harder to game and abuse, than a cap-and-trade system. It would engage free market forces rather than managing, circumventing, or smothering them in regulations.

Of course, the catch is that a proposed carbon tax would likely sail into the maelstrom of opposition that attends *any* new tax proposal. Many would argue that it would strangle economic growth. Others would worry that the burden of such a tax would fall disproportionately on society's most vulnerable citizens.

25 George P. Shultz and James A. Baker III, "A Conservative Answer to Climate Change" *Wall Street Journal*, February 8, 2017.

That said, some conservatives have explicitly embraced the option of a market-driven carbon emissions tax instead of government mandates and regulation of carbon emissions. Jerry Taylor of the libertarian Niskanen Center summarized it this way:

> Costly and economically inefficient command-and-control greenhouse gas regulations are firmly entrenched in law, and there is no plausible scenario in which they can be removed by conservative political force. Even were that not the case, the risks imposed by climate change are real, and a policy of ignoring those risks and hoping for the best is inconsistent with risk management practices conservatives embrace in other, non-climate contexts. Conservatives should embrace a carbon tax (a much less costly means of reducing greenhouse gas emissions) in return for elimination of EPA regulatory authority over greenhouse gas emissions, abolition of green energy subsidies and regulatory mandates, and offsetting tax cuts to provide for revenue neutrality.[26]

Note that Taylor does not simply advocate bolting a carbon emissions tax onto the existing jerry-built system of environmental regulations and tax breaks, but instead proposes a grand bargain of clearing away existing architecture in exchange for a carbon emissions tax.

Paraphrasing Winston Churchill's backhanded defense of democracy, *Weekly Standard* contributor Irwin M. Stelzer put the conservative argument succinctly: "Let's tax carbon: it's the worst form of energy policy, except for all the others that have been tried."[27]

One way to achieve this goal is a *revenue-neutral carbon emissions fee.* That idea has been championed by the Partnership for Responsible Growth (PRG), which takes a similar yet distinct approach from that advocated by Secretaries Shultz and Baker. The PRG proposes imposition of a gradually increasing fee on carbon at the source, the minehead or wellhead. The initial fee would be $35 per ton. Under this proposal, half of the $1.5 trillion to $2 trillion raised by such a fee would be used to reduce the U.S. corporate tax rate from 35 percent to 25 percent, bringing it into line with that of other Organisation for Economic Co-operation and Development (OECD) members. This would

26 Jerry Taylor, "The Conservative Case for a Carbon Tax," Niskanen Center, March 23, 2015, http://niskanencenter.org/wp-content/uploads/2015/03/The-Conservative-Case-for-a-Carbon-Tax1.pdf.

27 Irwin M. Stelzer, "Let's Tax Carbon," *The Weekly Standard*, May 26, 2014, http://www.weeklystandard.com/lets-tax-carbon/article/792852.

reduce the incentive for U.S. companies to move offshore. The other half of the carbon fee proceeds would be returned in some form of dividend to the low-income families disproportionately hit when the carbon fee translated into higher fossil fuel prices. In addition, the $35 fee would increase yearly to come closer to accounting for the full impact of CO_2 on the environment, thus driving more and more carbon out of the economy.

To avoid putting U.S. companies at a disadvantage to foreign competitors, this plan would include a tax adjustment—an additional duty at the border on imports from countries that do not tax carbon.

Why do we call this instrument a tax and not a fee, and what is the difference between the two? A variety of definitions and legal distinctions can be found, but essentially a tax is a measure to raise revenue "to defray the general costs of government," whereas a fee raises revenue "to pay for the costs of a specific government program or service."[28] People would be more likely to accept putting a price on carbon emissions if it were not labeled a "tax," and if the proceeds were pledged to finance tax cuts, but to classify the PRG's plan as a fee requires arguing that tax cuts constitute "a specific government program or service," a bit of a stretch. For its part, the Partnership calls its proposal "carbon-funded tax cuts."

This semantic finesse of a carbon emissions tax/fee would be worthwhile if it could leverage the power and efficiency of the marketplace to drive a low-carbon future. Burdening carbon emissions would help combat climate change, and using the proceeds to lower corporate taxes and to provide relief to the economically disadvantaged could blunt the intense opposition carbon emissions taxes invariably provoke.[29] It is not presented here as a panacea, but as a useful point of departure for discussing how best to lower the presence and impact of carbon on our planet.

28 Rebecca Helmes, "Extras on Excise: The Difference between a 'Tax' and a 'Fee' and Why It Matters," *Bloomberg BNA*, September 3, 2014, http://www.bna.com/extras-excise-difference-b17179894455/.

29 Partners for Responsible Growth, "Climate 2.0 Fact Sheet," accessed May 3, 2016, http://www.partnershipforresponsiblegrowth.org/fact-sheet.

2. Negawatts before megawatts: doubling down on efficiency

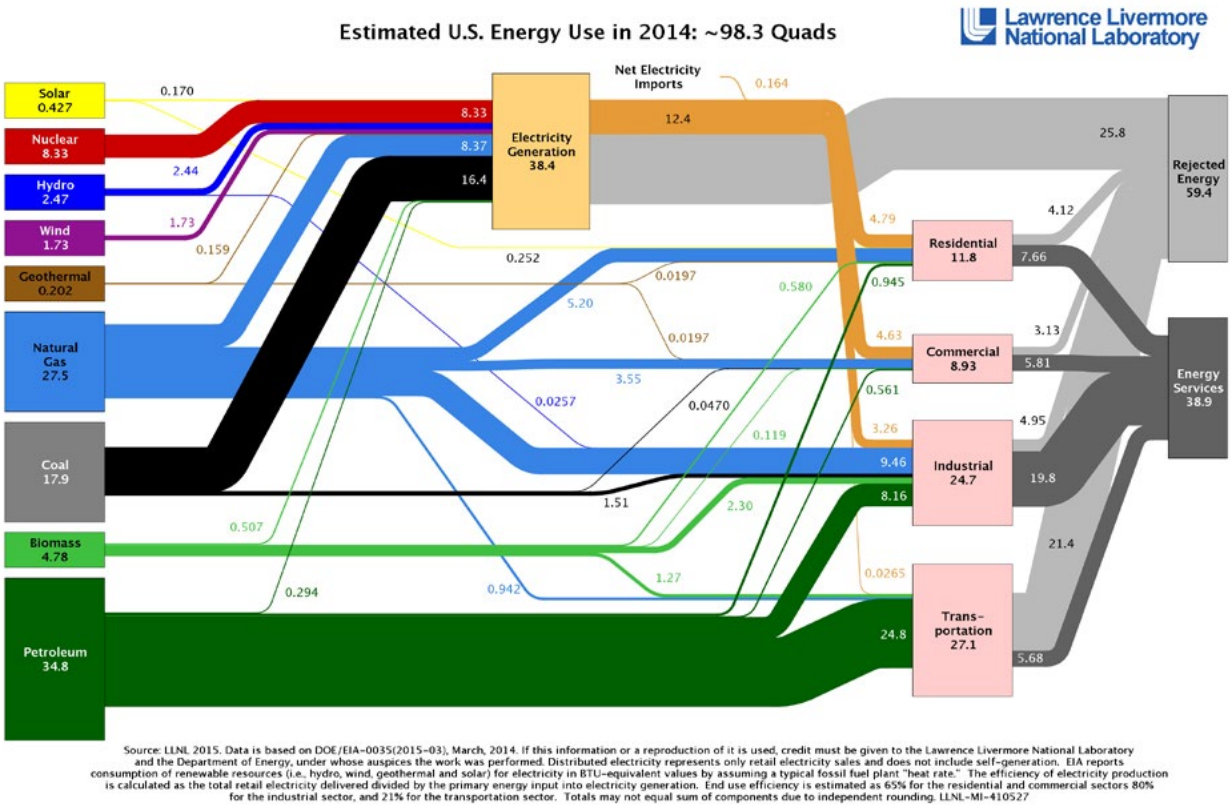
Even if a revenue-neutral carbon emissions fee were wildly successful, its effects would take a long time to work their way through the innovation cycle, from the point of emission to the point of consumption. The earth's atmosphere has been compared to a bathtub, where a "faucet" adds CO_2 emissions while a "drain" slowly removes it. Since the Industrial Revolution about 150 years ago, anthropogenic sources of CO_2 emissions in this "carbon cycle" have added about 30 percent more CO_2 to the atmosphere, while CO_2 removals have failed to keep pace. The bathtub will "overflow" when CO_2 has reached a level in the atmosphere that triggers a tipping point, after which catastrophic climate change cannot be avoided even if CO_2 emissions were immediately cut to zero.

Under this theory, since each molecule of CO_2 that is emitted remains in the atmosphere for generations, we must try to prevent the total stock of CO_2 from reaching that tipping point. A carbon emissions tax, though the most efficient, is far from the only way to fight back. For instance, if we could cut carbon emissions by reducing energy demand through increases in efficiency, that would also defer the day that our atmosphere reaches that tipping point.

Our current energy usage is grossly inefficient, presenting enormous opportunities for cutting carbon emissions. On a national scale, energy usage is often measured in quadrillion British thermal units, known as Quads. In 2014, the latest year for which data were available, 59.4 Quads out of a 98.3 Quad energy economy were wasted.[30] Of that wasted fraction, nearly two-thirds (38 quads) came from hydrocarbons. This wasted energy goes up the stack, out the window, or is simply lost in conversion from one form of energy to another.

Efficiency creates a win-win-win solution: Waste less, pay less, emit less.

30 Lawrence Livermore National Laboratory, "American energy use up slightly, carbon emissions almost unchanged," May 20, 2015, https://www.llnl.gov/news/american-energy-use-slightly-carbon-emissions-almost-unchanged-0



Source: LLNL 2015. Data is based on DOE/EIA-0035(2015-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

It also is essential to find additional ways to cut emissions from energy use in buildings. Buildings account for nearly 40 percent of U.S. energy consumption, and nearly 40 percent of our greenhouse gas emissions, taking into account emissions from the sources of power generation used to heat, cool, and operate them. Improvement will require changes in how buildings are designed and the kind of materials used (*e.g.,* insulation, sealants, windows), and in how energy is produced in buildings and is used in them (*e.g.,* heating and cooling systems, refrigerators, computers).[31]

In this sector we should also apply free-market principles to increase building efficiency and reduce emissions. Making overdue reforms to correct long-standing market imperfections could help. One problem is that many investments in improved efficiency are only attractive if the respective costs and benefits can be combined, but that only works if a single entity builds, owns, and occupies a building. Most buildings, however, have many stakeholders: developers, builders, owners, and occupants. These stakeholders, and their respective interests, are typically disaggregated.

31 Center for Climate and Energy Solutions, "Buildings Overview," May 2009, http://www.c2es.org/technology/overview/buildings.

Developers or builders who want to recover their investment after, say, two years, do not have incentives to put in better insulation or furnaces that would bring an attractive return on their investment after, say, three years. Building owners who are not a party to the deals until after buildings are complete have no opportunity to influence the developers or builders' decisions on efficiency investments, and in any event might simply pass higher energy bill costs on to their tenants. Incoming renters lack the opportunity to influence the up-front building decisions that affect their monthly energy bills and may not expect to stay in a building long enough for savings in monthly utility rates to justify their paying for whatever fraction of energy efficiency investments their landlord might impose on them.

In short, often the problem is not that the technology to improve efficiency is lacking or too expensive, or that it takes many years to earn back investments on energy savings, or that efficiency investments cannot produce attractive returns.[32] Instead, the problem is often a *market failure*, where savings and gains to all stakeholders are available, but no adequate mechanism exists to harness them in way that rewards efficiency commensurate to stakeholders' contributions. This suggests a second recommendation.

Recommendation 2: **Promote market mechanisms that reward efficiency.**

Fortunately, several mechanisms have been introduced to address these problems. An energy savings performance contract (ESPC) seeks to unify these disaggregated interests so that the collective upside of energy efficiency investments can be captured. Here is an example of how they can work. An Energy Service Company (ESCO) enters an agreement with a building owner to perform an energy assessment of the building, which forms the basis for investment options in various building upgrades—furnace, HVAC, insulation, roof, door, and window treatments. The building owner selects a set of

32 McKinsey & Company, *Energy Efficiency: A Compelling Global Resource*, 2010, https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/Sustainability/PDFs/A_Compelling_Global_Resource.ashx.

options, and the ESCO offers a fixed-price contract that includes the cost of the work and guaranteed cost and energy savings over a number of years.[33]

Under this ESPC, the ESCO borrows the necessary funds and makes the initial investment. The result is that the building owner benefits from the cost and energy savings, the ESCO earns the difference between its costs and the fixed price agreed upon with the owner, and society benefits from the energy and carbon emission reductions that would not otherwise have been achieved.

The ESPC model can be a powerful driver of energy efficiency, and federal leadership can help lead the way. In 2009 President Obama signed an executive order to reduce energy intensity in the nearly 500,000 buildings owned by the federal government, leveraging the power of large-scale federal purchasing to effect change. Nearly six years later, he signed another executive order that instructed federal agencies to cut greenhouse gas emissions 40 percent from 2008 levels by 2025 through reducing energy intensity and increasing the use of renewable energy.[34]

The Department of Defense alone owns 345,000 buildings that amount to 2.2 billion square feet under roof—almost six times the area of real estate owned by the General Services Administration. By 2016 the Navy had over $1 billion in ESPC contracts in the pipeline to help it achieve its goal of reaching 50 percent renewable power by 2020.[35]

ESCOs are market-friendly tools that do not seek to overrule markets, but rather to unleash their potential by capturing potential earning streams that already exist but are not monetized due to markets that do not recognize their value. So perhaps more can be done to unleash their potential. For example, state, local and municipal governments—with advice from the U.S. Department of Energy (DOE)—could use their convening power to bring ESPCs, local housing authorities, and owners of homes or multifamily dwellings with a view to unleashing the power of the ESCOs in as-yet-unprofitable markets, such as the residential market. The average homeowner hasn't got the time

33 T. Tetrault and S. Regenthal, "ESPC Overview: Cash Flows, Scenarios, and Associated Diagrams for Energy Savings Performance Contracts," National Renewable Energy Laboratory, May 2011, http://www.nrel.gov/docs/fy11osti/51398.pdf.

34 The White House, "Executive Order No. 13693, Planning for Federal Sustainability in the Next Decade," March 19, 2015, https://www.whitehouse.gov/the-press-office/2015/03/19/executive-order-planning-federal-sustainability-next-decade.

35 Further information on ESPCs can be found on the DOE website, at https://energy.gov/eere/femp/energy-savings-performance-contracts-federal-agencies.

and energy to think about how to save a few dollars a month on energy, but an ESCO could take that burden from them. In addition, a number of entrepreneurs are looking at various ways for utilities to work with homeowners and business owners and make as much money selling "negawatts" as megawatts.[36]

Part of the problem has been a lack of accurate, integrated data on cost and energy savings available through different building materials and technologies. The Lawrence Berkeley National Laboratory tackled this problem by building FLEXLAB, a cutting-edge facility with four test beds that allow comparison testing of competing technologies as well as analysis of HVAC systems, lighting, windows, building envelope, control systems, and appliances. It facilitated an integrated analysis of three elements often tested in isolation—building skin and treatments, appliances and other plug loads, and behavioral issues. Using tools like FLEXLAB, owners, developers, architects, engineers, and constructors can work together on buildings that are cheaper to own and operate, more pleasant and productive places to live, work, and play—all while cutting CO_2 and fighting climate change.

3. Ramping up low-carbon power generation: the role of clean energy finance

The story of renewable energy in the United States has been transformed in recent years. From 2007 to 2011, installed renewable power generating capacity doubled, from 31 GW to 62 GW, and from 3 percent to nearly 6 percent of the U.S. total capacity. Looking beyond capacity to power generated, from 2005 to 2015 renewables grew from 8.8 to 13.4 percent of U.S. energy sources.[37] Wind and solar power generation have climbed to a higher share of installed capacity than of power generated, because these intermittent energy sources only generate power when the sun shines or the wind blows, unlike nuclear or fossil plants that generate power continuously.

36 IIP Digital, US Department of State, "Energy Entrepreneur makes Less into More", Accessed January 2016, http://iipdigital.usembassy.gov/st/english/article/2011/08/20110810164705kram0.7714502.html?CP.rss=true#axzz1UitQbpkw

37 Energy Information Administration, "Electricity Monthly Update," March 24, 2016, http://www.eia.gov/electricity/monthly/update/archive/march2016/.

Many factors contributed to the expansion of wind and solar energy plants, including tax policy. The Energy Policy Act of 1992 established a production tax credit (PTC) for renewable energy projects based on the amount of power they actually produced. The Energy Policy Act of 2005 created a 30 percent investment tax credit (ITC) on funds invested in commercial and residential solar energy systems. [38] And the Recovery Act of 2009 added temporary manufacturing tax credits as well as cash payments in lieu of tax credits to support billions of dollars of investment in renewable energy.[39] The PTC has been increased from 2.2 cents to 2.3 cents per kilowatt hour and extended for several more years; it will scale down until it expires in 2020. The ITC will taper from 30 percent to 10 percent in 2022.

Wind power benefited tremendously from the PTC. With improved technology driving down the costs of land-based wind power, the few cents advantage was significant to achieving grid parity with other forms of power generation, driving further investments into the sector. By 2012 wind power comprised 40 percent of the new power installed in the United States, receding by 2016 to 23 percent as natural gas and solar power plants picked up pace. By the end of 2015, the national total for wind stood at 73 GW installed capacity.[40]

According to the EIA and IEA, onshore wind energy will make up the largest share of alternative energies by 2040. By 2015, wind power supplied 3 percent of energy demand in China and 4 percent in the United States, but over 20 percent in Spain and Portugal, and up to 40 percent in Denmark.[41] Technological improvements, including larger rotors, have further reduced the price of electricity generated by wind power to where it competes with increasing

38 Jenna Goodward and Mariana Gonzalez, "Bottom Line on Renewable Energy Tax Credits," World Resources Institute, October 2010, http://www.wri.org/publication/bottom-line-renewable-energy-tax-credits.

39 The White House, "FACT SHEET: The Recovery Act Made the Largest Single Investment in Clean Energy in History, Driving the Deployment of Clean Energy, Promoting Energy Efficiency, and Supporting Manufacturing," February 25, 2016, https://www.whitehouse.gov/the-press-office/2016/02/25/fact-sheet-recovery-act-made-largest-single-investment-clean-energy. Regarding the Recovery Act tax programs, Phase II of the 48C ITC made $150 million of unused tax credits from the $2.3 billion Phase I credits available again for use through 2017, http://energy.gov/sites/prod/files/2013/04/f0/FACT%20SHEET%20--%2048C%20MANUFACTURING%20TAX%20CREDITS.pdf. The 1603 Program expired on December 31, 2011, but projects that started construction before that date were still eligible to receive the award, http://www.nrel.gov/docs/fy12osti/53720.pdf, ii.

40 Energy Information Administration, *Today in Energy* (March 1, 2017) http://www.eia.gov/todayinenergy/detail.php?id=25172; Energy Information Administration, *Today in Energy* (November 28, 2016), http://www.eia.gov/todayinenergy/detail.php?id=28912

41 International Energy Agency, "IEA Wind: 2014 Annual Report," August 2015, http://www.ieawind.org/annual_reports_PDF/2014/2014%20AR_smallfile.pdf.

success against fossil fuel plants.[42] The EIA projects onshore wind will produce 319 billion kilowatt hours of electricity by 2020, growing at a rate of 2.2 percent over the next 30 years and overtaking hydropower as the largest renewable source of electricity in the country by 2040.

While wind makes up the biggest share for alternative renewables, solar is the fastest growing technology, with annual growth rates of 7 percent projected through 2040.[43] That growth is driven in large part by the federal ITC, which provides a 30 percent credit against the tax liability of utility, commercial, and residential investors in solar power assets. It has subsidized widespread deployment of solar panels on individual rooftops, enabling homeowners not to rely exclusively on centralized power plants.

This approach departs from the classic hub-and-spoke, investor-owned utility model of massive power plants supplying huge amounts of electricity to the grid. Instead, under this model, called "distributed generation," when the solar panels provide more electricity than homeowners need, they are authorized by most states to sell the excess power to utilities, but when the panels do not provide enough electricity, utilities sell power to the homeowner. The homeowners end up paying for the amount of electricity consumed from their utility, net of the amount of electricity sold back to the utility—a rate-paying model called "net metering." Advocates of net metering assert that residential solar helps smooth demand spikes while ultimately supporting the stability of the grid, without excessive burden to non-solar-using ratepayers.[44]

As deployment of rooftop solar has increased in recent years, so has utilities' opposition to net metering. The problem, in their eyes, is that when utilities buy power from homeowners, they are required to pay retail prices for that power. That is expensive power for utilities to buy since they can either generate their own power or buy wholesale power more cheaply. This practice causes electricity prices to rise overall, effectively taking money from ratepayers without rooftop solar panels and giving it to ratepayers with rooftop solar panels.

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42 Energy Information Administration, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2015," June 3, 2015, http://www.eia.gov/forecasts/aeo/electricity_generation.cfm.

43 Energy Information Administration, *Annual Energy Outlook 2015 with Projects to 2040*, April 2015, Table A16, http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf.

44 http://www.solarabcs.org/about/publications/reports/rateimpact/pdfs/rateimpact_full.pdf

In addition, retail prices reflect not only incremental cost of the power generated, but also all the associated fixed costs of the installed generation base, transmission, and distribution, and a return to the investor. So net metering essentially *pays* rooftop solar owners for all those costs of the grid (which they did not incur) instead of *charging* for them, as they do with all other ratepayers. This raises questions of fairness, because rooftop solar owners still benefit from the grid when the sun is not shining, so once again traditional utility customers are effectively subsidizing rooftop solar owners for the latter's use of the grid. And since rooftop solar owners tend to be more affluent, this redistribution of resources is regressive in effect.

One obvious way to redress this subsidy is simply to pay rooftop solar owners *wholesale* prices for the electricity they sell to the utility, which would lower utility-based rates overall and avoid the distortion of some ratepayers subsidizing other ratepayers' use of the grid.[45]

There are other tools that can promote the use of solar power without the regressive and distorting effects of net metering. One is investment in driving down the costs of solar power. Tax credits aside, the levelized cost of electricity for grid scale solar photovoltaic power still costs almost 16 cents higher per kilowatt hour compared to wind power and 18 cents higher compared to conventional combined cycle natural gas-fired plants.[46]

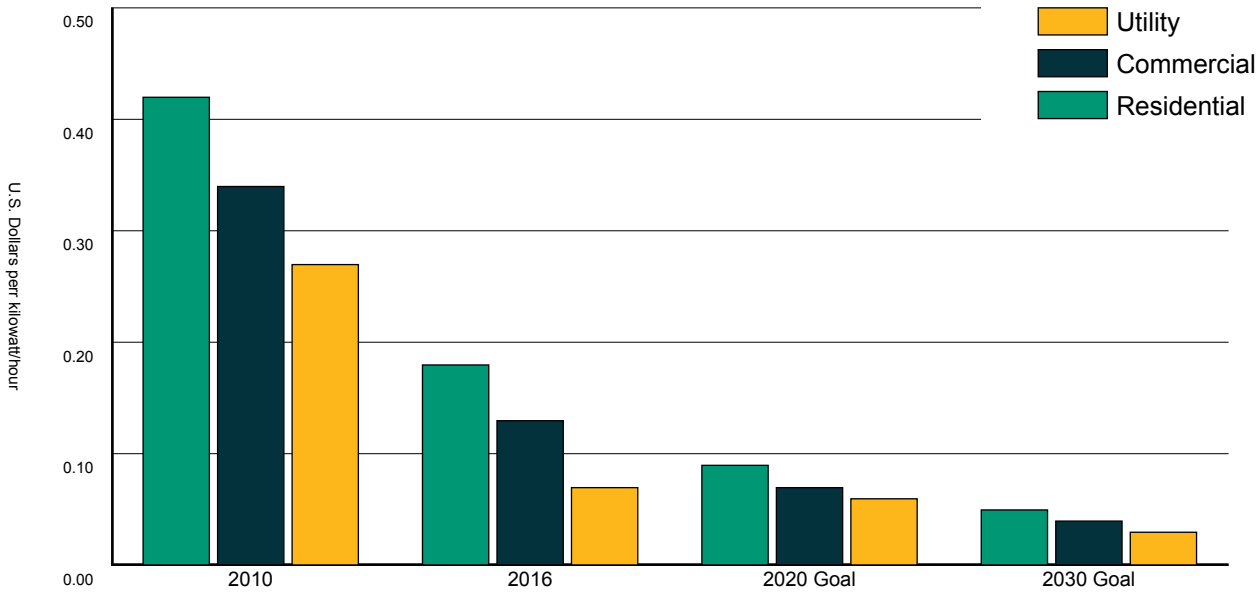
To address this problem the U.S. Department of Energy in 2011 launched the "Sun Shot" program, modeled on President John F. Kennedy's 1961 moon shot initiative. The Sun Shot program provided research grants to stimulate progress in cost reduction, improved efficiency, enhanced manufacturing, and other tools to bring down the levelized cost of solar power from 21 cents to 6 cents per kilowatt hour without incentives. That price would mean that solar power had achieved "grid parity," or the ability to compete successfully against the electricity rates of traditional sources of power generation. Within five years of its launch, Sun Shot had already achieved 70 percent of its 6-cent goal. (To be fair, a number of other factors

45 Forty-four states, the District of Columbia, and four territories now authorize net metering policies, while two other states permit utilities to apply net metering. Another problem with net metering is that excess production from the homeowners can flow back into the grid, potentially overloading substations, producing high-voltage swings, and damaging equipment; MIT, *Future of the Electric Grid* (Cambridge, MA: MIT, 2011): 16–18.

46 Energy Information Administration, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016" (August 2016) https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

helped drive down the cost of solar power, including falling silica prices and enormously overbuilt capacity to manufacture solar panels in China, leading overall to a supply glut that lowered prices everywhere.)

Progress of "Sun Shot" program, DOE



Despite this progress, however, utility-scale solar photovoltaic power still only generates about 15 percent as much electricity in the United States as does wind power, and less than 1 percent of total power generated from all sources.[47]

The most important limitation on the role that wind and solar power can play in meeting America's power generation requirements is intermittency; availability of sunshine or wind does not always track electricity demand. Until grid-level energy storage becomes ubiquitous at competitive prices, or improved technology and business models allow *much* better fine-tuning of electricity supply and demand on a minute-to-minute basis, wind and solar power will need to be integrated into a system that combines continuously available base-load power to meet the minimum demand required on

47 Energy Information Administration, *Electric Power Monthly* (February 24, 2017) https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01_a; https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01

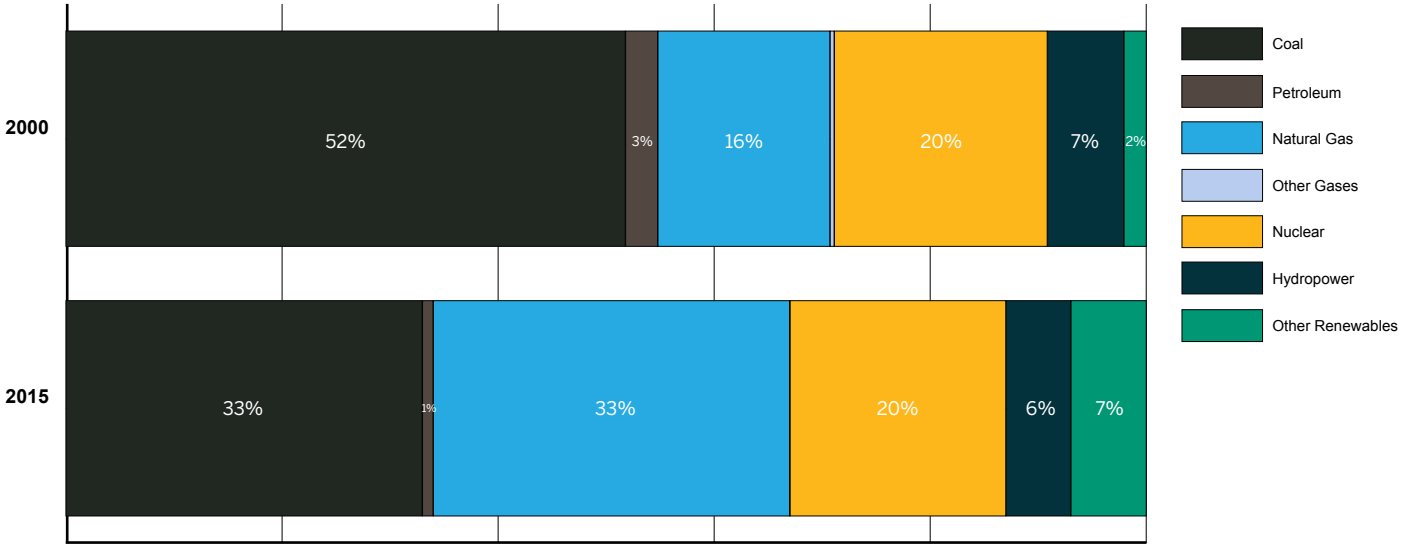
a particular grid with a "peaker"—a power source that can quickly be dispatched to cover the peak loads that grids experience. Traditionally, nuclear and coal-fired plants have served base-load requirements, while gas-fired turbines have become the peakers of choice.

Thus, wind and solar power will supply an increasingly important carbon-free component in our national power mix, but one that will continue to depend on complementary contributions from base-load and peak-load sources of power. The public policy challenge will be to increase the carbon-free percentage of those additional power.

In Europe "feed-in tariffs"—price subsidies granted to renewable energy technologies—have been used to increase deployment of renewable energy solutions. But feed-in tariffs impose a penalty on the standard of living of families forced to pay higher electricity rates. When a recession hits or the economic burden these tariffs impose otherwise becomes too great, governments—such as those in Spain, Germany, Italy, and the Czech Republic—suspend or curtail these subsidies. When that happens, investors and generators suffer, undermining the expectations underpinning their original investment and betraying a basic design flaw in the feed-in tariff business model.

In the United States, in addition to the PTCs and ITCs, much of the growth in renewable energy has been generated by specific mandate, such as the renewable portfolio standards (which require that a certain percentage of all power generation in a state be comprised of renewable sources), or other incentives favoring renewable energy. But these policies perpetuate a public policy flaw by focusing only on renewability when the primary objective is to lower carbon. Instead of perpetuating subsidies that subsidize only some low-carbon power sources but not others, we ought to be encouraging the maximization of all low- or no-carbon alternatives, either through even-handed subsidies or, ultimately, by replacing all subsidies by a tax on carbon emissions.

Evolution of power generation mix in U.S., 2000 to 2015



The PTC, for example, currently favors wind generators over nuclear power generators.[48] Why? Because in merchant power markets, the decision of which power generator gets to supply power is made by auction. Generators of coal, gas, wind, sun, and nuclear power each bid the price at which they are willing to sell their power to the system operator. The system operator then agrees to dispatch power from the cheapest bid first, second cheapest bid second, and so forth, until the full demand load is met. The highest-priced bid needed to meet the current load becomes the "clearing price," and all bidders are paid that price by the system operator, even though most bid at lower prices.

Because nuclear power plants are so capital intensive, and fuel accounts for such a small percentage of their total costs, nuclear operators typically bid in their power at a price of zero to guarantee that their bid will be accepted and their power will all get dispatched. Since the marginal cost of operating nuclear power plants tends to be relatively low, the clearing price will typically bring in sufficient revenues to cover their operating expenses and provide some return on invested capital. But with the abundant shale-gas production in the United States driving natural gas prices lower and lower, those margins have been shrinking. And with a 2.2 cents subsidy per kilowatt-hour generated, wind generators can make money *even if they bid at a price less than zero!* But nuclear plant operators cannot afford to operate at a loss, and have long argued that

48 The new nuclear power plants now under construction at the Vogtle and Summer sites may also benefit from production tax credits under the Energy Policy Act of 2005 if they enter into service by 2020.

the PTC has served its purpose of nurturing the wind industry to maturity and should be eliminated.[49] That PTC is now slated to phase out by 2020.

This is not to suggest that tax policy or public finance have no role in promoting renewable energy. Such a position might be appropriate in the presence of a realistic price on carbon emissions, combined with a tax reform that removed *all* government incentives from the tax code. But it does suggest our third recommendation.

Recommendation 3: **Level the playing field for all lower-carbon energy sources.**

The implication of this recommendation is that any mandatory standards imposed by governments on source of power generation should be framed as "clean"—i.e. low carbon—rather than as purely "renewable" portfolio standards. President Obama called for such a clean energy standard in his 2011 State of the Union address, arguing that instead of "subsidizing yesterday's energy, let's invest in tomorrow's." That would give equal credit to all zero-carbon power sources, including nuclear, while giving proportionate credit for natural gas (which emits just half the greenhouse gases as coal) and for coal plants with carbon capture and sequestration investments.

The Clean Energy Standard reflected an "all-of-the-above" approach to providing for the Nation's energy, which supported the development of fossil fuels, renewables, nuclear, and energy efficiency, on the following theory:

> A Clean Energy Standard is a flexible, market-based approach that will set annual targets for electricity from clean energy sources, while allowing businesses and entrepreneurs to determine the best way to achieve them—ensuring that clean energy will be produced wherever it makes the most economic sense.[50]

49 Anthony J. Alexander, Christopher M. Crane, and Thad Hill, "The PTC Is No Longer Needed to Support The Wind Industry," *Forbes,* October 23, 2014.

50 Nat Keohane, "A Clean Energy Standard for America," *White House Blog,* March 2, 2012, https://www.whitehouse.gov/blog/2012/03/02/clean-energy-standard-america.

As owner of 360,000 buildings and over 650,000 fleet vehicles, and spender of $445 billion on goods and services each year, the federal government is well-positioned to help drive investments toward cleaner energy sources. The power of the federal government as both a producer and a consumer to cut carbon emissions was invoked through Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic* Performance. The order required designation of a senior sustainability officer in each federal agency, each of which was required to set targets to reduce its own greenhouse gas emissions from its own activities, from sources of power it purchased, and from sources found in its supply chain.[51]

While admirable in its commitment to federal leadership in cutting greenhouse gas emissions, the executive order erred in not following the President's own commitment to "clean" energy standards, citing only "renewable" energy and not nuclear energy as an alternative to fossil fuels. In 2015 the president signed a new executive order, EO 13693, that called for federal agencies to cut greenhouse gas emissions by 40 percent by 2025 from 2008 levels, but he perpetuated the earlier error by calling on agencies also to increase their electricity consumption from "renewable" sources to 30 percent.

Despite the fact that over 60 percent of U.S. carbon-free electricity comes from nuclear power, the only nuclear power given credit under the new executive order was for small modular reactors, still a decade or more away from deployment.

To be clear, there is nothing wrong with renewability; the idea of free "fuel" in the form of solar and wind energy is indeed attractive and economically elegant. Nor is there anything wrong with small modular reactors, an exciting and promising avenue toward a low-carbon future. That said, neither renewable sources of energy nor small modular reactors can match the quantities of carbon that current generation nuclear power displaces from the atmosphere in the here and now. To be sure, today's nuclear industry faces serious challenges, which we will explore in detail in the next section, but wind power also has critics among those who do not like seeing pristine vistas spoiled by rows of wind turbines or who worry about the problem of bird kills. And solar power threatens to cover vast swaths of virgin terrain with panels or mirrors,

51 Executive Order 13514, *"Federal Leadership in Environmental, Energy, and Economic Performance"*, Signed by President Obama on October 5, 2009. Accessed via https://www.fedcenter.gov/programs/eo13514/

disrupting fragile ecosystems, while also requiring the addition of unpopular long-distance transmission lines to bring solar energy to urban centers.

Case study: **The Loan Guarantee Program and its progeny**

Part of leveling the playing field for clean energy sources requires lowering their capital costs. First, where the price of fuel is zero (wind, solar, hydro, geothermal) or modest (nuclear), but the up-front capital investment is high, the capital cost is the dominant factor in clean energy industries' economic competitiveness vis-à-vis coal and natural gas plants. Second, in a world where there is no price on carbon emissions *and* several tax benefits favoring fossil fuel use, providing tax benefits or credit enhancements for clean energy investments can further help level the playing field. This is where the Department of Energy (DOE) Loan Guarantee Program provided important benefits by lowering the cost of capital and thereby facilitating the greening of America's power sector.

In reviewing the Loan Guarantee Program, it is important to recall how tough it was to finance clean energy in 2009. The United States was in the depth of the sharpest recession since the Great Depression, millions were out of work, and commercial credit was extremely tight following the collapse of Lehman Brothers. Clean energy projects at grid scale did not have a track record of finding finance in public capital markets, there was no price on carbon emissions, and developers were hard pressed to demonstrate that clean energy projects could generate high enough returns to attract private equity investors. While photovoltaic technology was well established, that technology had never been deployed at grid scale (i.e. 100MWe or more) in the United States.[52] Under the American Reinvestment and Recovery Act, passed by Congress and signed by President Obama in February 2009 to help revive the U.S. economy at a time when employment was declining on average by over 750,000 jobs per month

The DOE Loan Guarantee Program invested $30 billion from the Recovery Act to fund DOE loans and loan guarantees. That investment in turn leveraged

52 Megan M. Barker and Adam A. Hadi, "Payroll Employment in 2009: Job Losses Continue," *Monthly Labor Review*, Bureau of Labor Statistics, March 2010, 23. According to the authors, "Employment declined by 4.7 million in 2009, the largest calendar-year job loss in the history of the series (since 1939)."

a further $50 billion in support of twenty projects. Through these projects, the Loan Guarantee Program helped clean energy technologies traverse the "second valley of death." The first valley of death for new-technology start-ups is well known; with thousands of creative and innovative ideas out there, only a handful manage to attract sufficient capital to take them from conception through computer simulation to prototype, demonstrating to investors along the way that a new technology is robust and commercially viable.

Traditionally the DOE has helped technologies seeking to traverse that first valley of death. Whether through the inspired work of the seventeen national laboratories, or by making user facilities available to tens of thousands of researchers outside of the national labs, or by using vigorous peer review to select candidates to receive public funding, the Department of Energy has been a powerful driver of American innovation.

The second valley of death occurs *after* a new technology has been demonstrated to work at bench or prototype scale, but *before* it has been deployed at commercial scale. This was the valley the DOE Loan Guarantee Program aimed to bridge by, for example, providing the credit enhancements necessary to get the first ever grid-scale solar photovoltaic plant built in the United States. After the Loan Guarantee Program financed the first five such projects in the country, the private sector financed the next ten. The program also financed the introduction of the first-ever grid level concentrated solar power plants in the United States, the largest wind farm in the United States, a biofuel project in Kansas, three geothermal plants, the first commercial nuclear power plant to be built in thirty years in the United States, and advanced technology manufacturing facilities for Ford, Nissan, and Tesla.[53]

As of September 2015 these projects avoided 25 million metric tons of CO_2 emissions, avoided consumption of 1.35 billion gallons of gasoline, displaced 5.28 million automobiles from the road, and provided sufficient power for one million homes. At the same time, they created or saved fifty-six thousand American jobs.[54]

53 Of course, other tools—such as long-term power purchasing agreements—also help reduce the risk of deploying low-carbon power sources and, indeed, helped support the underwriting for the power generation projects supported by the Loan Guarantee Program.

54 U.S. Department of Energy Loans Programs Office, "Financing Innovation to Address Global Climate Change," December 2015, http://www.energy.gov/sites/prod/files/2015/12/f27/DOE-LPO_Report_Financing-Innovation-Climate-Change.pdf.

This praise for the Loan Guarantee Program may seem ill-placed to those whose sole familiarity with it derives from its most notorious failure: Solyndra. Solyndra, a manufacturer of unusual cylindrical solar modules, obtained the first loan guarantee approved by the DOE. Though the MIT publication, *Technology Review*, declared Solyndra to be one of the 50 most innovative companies in the world, the company eventually went bankrupt, costing taxpayers more than $500 million when it defaulted on its loan.[55] Nevertheless, the total default rate in the DOE Loan Guarantee portfolio was just 2 percent, and less than 10 percent set aside by Congress as a loan-loss reserve to support the program has been consumed as of this writing. Given that by statute the Loan Guarantee Program was intended to support a new class of investments—some of which needed to be innovative to qualify for support—such a modest default rate is quite impressive and would be envied by many a private sector portfolio manager.[56]

Overall this series of DOE loan guarantees enabled the construction of a number of clean energy projects that have entered into operation and are generating reliable cash flows, producing 6–9 percent unlevered returns under long-term power purchasing agreements.[57]

This new asset class gave rise to a new investment vehicle—the renewable yieldco—which bundles a number of projects into a single investment vehicle after their construction is complete and they are producing predictable cash flows. Once bundled, these cash-generating projects are "spun off" into

55 A detailed review of the Solyndra matter can be found at U.S. Department of Energy, Office of Inspector General, *Special Report: The Department of Energy's Loan Guarantee to Solyndra, Inc.*, August 24, 2015. For an independent view of the status and risks of DOE's loan portfolio and recommendations for enhancing early warning systems and management of the portfolio, see *Report of the Independent Consultant's Review with Respect to the Department of Energy Loan and Loan Guarantee Portfolio*, January 31, 2012, https://www.whitehouse.gov/sites/default/files/docs/report_on_doe_loan_and_guarantee_portfolio.pdf

56 The legislative authority for the loan guarantee programs was granted in Title XVII of the Energy Policy Act of 2005, and had several legislative authorizations. Section 1703 supported loan guarantees for technologies that avoid, reduce, or sequester air pollutants or anthropogenic emissions of greenhouse gases and not be of general commercial use, http://energy.gov/lpo/services/section-1703-loan-program. Section 1705 was added under the 2009 American Reinvestment and Recovery Act, with a view to launching programs quickly in order to help bring the U.S. out of recession. It supported projects that started before September 30, 2011, and "involve certain renewable energy systems, electric power transmission systems, and leading edge biofuels." http://energy.gov/lpo/services/section-1705-loan-program. Finally, loans under the Advanced Technology in Vehicle Manufacturing program (ATVM) program must be for reequipping, expanding, or establishing manufacturing facilities in the U.S. to produce advanced technology vehicles or engineering the integration of qualifying components that meet higher efficiency standards, http://energy.gov/lpo/services/atvm-loan-program.

57 Richard Kauffman, "Seizing a Clean Energy Opportunity," August 10, 2012, http://www.energy.gov/articles/seizing-clean-energy-opportunity FIND ORIGINAL KAUFFMAN ARTICLE (BHH note—here is the original article: http://www.huffingtonpost.com/richard-kauffman/a-clean-energy-opportunity_b_1761543.html?)

separate, publically traded companies. The concept addressed one of the chronic problems in the field of clean energy finance: there are few large institutional investors with the capability either to perform adequate due diligence or to muster the cash needed to invest in one-of-a-kind (and initially first-of-a-kind) projects.

By taking these projects out of the realm of pure project finance and bundling many of them into a new investment vehicle that can be sliced up into thousands of individual investor-sized shares, yieldcos de-risk an investment while widening the pool of investors who can purchase the shares. This lowers the cost of capital along with the risk, providing investors with the prospect a more stable investment option than they would get by investing in just one renewable asset. And while asset prices for renewable projects were rising, and more such projects were getting built, yieldcos offered both growth opportunities and steady dividend streams.

Unfortunately, from the heady days of its introduction in 2013, the yieldco quickly traced a boom-bust cycle that raised questions about its utility as a clean energy financing tool. The initial wave of enthusiasm led to the launch of a number of yieldcos that raised $16 billion through mid-2015. But the dividends from yieldcos were enhanced by their ability to use the net operating losses generated by renewable energy projects through asset depreciation and tax credits to offset their corporate tax liability. So for yieldco performance to be sustained as their portfolio assets depreciated and tax credits diminished, they needed to keep adding new renewable projects to generate net operating losses.[58] But exuberance over the new yieldco vehicle led sponsors to launch more yieldcos than the supply of dividend-yielding assets could support. Recognition of that fact led investors to lose confidence in yieldcos, which in turn drove down demand for—and hence prices of—yieldco shares.

In addition, although initially they were thought to be insulated from oil markets, the steep drop in oil prices in 2014 ended up chilling investments in yieldcos.[59] Moreover, yieldcos use the net operating losses facilitated by the production tax credit (for wind projects) and the investment tax credit (for

58 Zekun Lui, "Why Renewables Deserve MLP Parity," *ACORE Blog,* September 30, 2015, http://www.acore.org/acore-blog/item/4219-why-renewables-deserve-mlp-parity.

59 Tom Konrad, "The YieldCo Boom and Bust: The Consequences of Greed and a Return to Normalcy," Greentech Media, May 13, 2016, https://www.greentechmedia.com/articles/read/the-yieldco-boom-and-bust-the-consequences-of-greed; Jay Yao, "Is the Yieldco Business Model Dead?" The Motley Fool, March 26, 2016, http://www.fool.com/investing/general/2016/03/26/is-the-yieldco-business-model-dead.aspx.

solar projects) to offset corporate tax liability, which means that once those credits are phased out the yieldco model will lose much of its attraction.

This raises the question, Is the yieldco model viable? Was the premise valid? Or was it a flash in the pan? While a combination of overinvestment, diminishing renewable energy deal flows, and falling fossil fuel prices battered yieldco prices, the basic idea of bundling and securitizing clean-energy projects so that they can be sold at a relatively modest share price remains valid.[60] To facilitate yieldcos, it is important to assure sufficient standardization of project terms and power purchasing agreements, to ensure the assets being bundled are in fact comparable. This is *unlike* the good and bad mortgages bundled into securitized assets during the housing bubble that nearly cratered the U.S. economy in 2007 and 2008. That way investors can clearly see what they are buying— and that in fact that they are investing in securitized instruments with strong underlying assets that are protected by appropriate contractual terms and conditions. Some investors still have an appetite for assets that yield stable, long-term cash flows even at modest returns in a yield-starved world. Meanwhile, developers of renewable power projects could still benefit from reducing their cost of capital. This may enable the yieldco to remain an attractive investment instrument to drive clean energy investment in the years ahead.

Another way to promote clean energy projects would be to make them eligible to be included in Master Limited Partnerships (MLPs) or Real Estate Investment Trusts (REITs), instruments that have drawn billions of dollars of investment capital at interest rates far more favorable than typically borne by developers of clean energy projects. Both MLPs and REITs permit investors to avoid double taxation, i.e. paying taxes on income at both the corporate and the individual level. Indeed, interest in yieldcos was based in part on clean energy projects' ineligibility for tax benefits derived from inclusion in MLPs and REITs.

How could MLPs and REITs support clean energy investments?

Given their preferential tax treatment, MLPs can attract investors with lower interest rates, which boosts the net income derived from these long-term investments that generate stable, long-term cash flows. The lower cost of

60 Tom Konrad, "10 Clean Energy Stocks for 2015: Income Comes in First; Growth Shrinks," *SeekingAlpha*, January 12, 2016, http://seekingalpha.com/article/3806676-10-clean-energy-stocks-2015-income-comes-first-growth-shrinks.

capital available to MLPs therefore brings substantial new investment to MLP projects, such as the horizontal drilling infrastructure that underpinned the massive expansion of natural gas production in the United States.

Currently, to qualify for MLP status, a partnership must generate at least 90 percent of its income from "qualifying" sources, such as activities related to the production, processing, and transportation of oil, natural gas, and coal. There is no logical reason why clean energy projects backed by long-term power purchasing agreements should not also be eligible to use MLPs to lower their capital costs and level the playing field vis-à-vis fossil-fueled projects. But they have not been granted eligibility.

Why are MLPs allowed to finance fossil fuel projects that pollute the air and warm the climate but not projects that do *not* pollute the air and warm the climate? The answer is that political forces converged behind the introduction of MLPs back in 1981 to support natural gas pipeline construction, but in the 2010s both Congress and the executive branch have resisted further widening of tax loopholes and associated government deficits.

Some in Congress, however, have shared the view that as long as MLPs are permitted to finance fossil fuel projects, then they should be permitted to finance clean energy projects too. The MLP Act, introduced with strong bipartisan support in 2015, proposed expanding the scope of the qualifying income to include renewable energy. Time will tell whether the new climate in Washington will favor its passage and enactment.

Unlike MLPs, however, using REITs for renewable energy projects does not require amending the Internal Revenue Service code. REITs have been around since the 1960s and provide tax-favored treatment for investors in commercial real estate projects.[61] And the logic that clean energy projects should receive no less favorable tax treatment than fossil fuel projects in accessing the MLP market applies equally to their treatment vis-à-vis hotels, shopping malls, warehouses, highway billboards, and the myriad of other real estate projects that have enjoyed access to favorably-priced equity for decades. Despite that logic, the Obama administration declined to make that administrative change

61 According to the SEC, to qualify as a REIT an entity must pay at least 90 percent of its taxable income to shareholders in the form of dividends, be managed by a Board of Trustees, primarily own real estate assets, derive most of its income from passive sources, and be owned a by a diversified set of at least one hundred shareholders, https://www.sec.gov/answers/reits.htm.

in interpreting the cost code because of concerns that tax revenues lost due to widening REIT availability would drive up the deficit.

That was a mistake. While allowing clean energy projects access to REIT treatment would indeed have lost tax revenues, it would have leveraged billions of dollars from public capital markets to drive investment into this sector, accelerating the creation of a low-carbon energy economy and saving all of the costs that carbon emissions impose on society while combating climate change.

The point here is not to argue for a continued proliferation of special tax advantages for clean energy projects. As stated earlier, the cleanest and simplest way to favor clean energy investments is to put a burden on carbon emissions, which would drive investments to favor carbon-cutting alternatives. But in the absence of that kind of across-the-board, even-handed approach, it makes sense to take those tax-code provisions that promote investments that, at best, are no *more* virtuous than clean energy projects (*e.g.*, natural gas pipelines and highway billboards) and make them equally available to clean energy projects.

6. Investing in innovation: the need to lead in science

The strength of our Nation derives from many factors, including the tremendous bounty endowed by nature in the form of vast energy resources of many varieties—fossil fuels, bio-fuels, uranium, hydro, and geothermal. Our greatest resource, however, is the American people—a melting pot of creative, innovative, and motivated individuals from all over the world. While recent years have been hard on many Americans who have lost their jobs or seen their wages stagnate, the free market economy of the United States still rewards innovation and affords opportunity to new products, services, and ideas.

The free market, however, is not well designed for all purposes. Specifically, it does not do well at promoting public goods, which by definition benefit society as a whole but cannot easily be compartmentalized and assigned to particular individuals for their personal use or enjoyment. That is why public goods, such as providing for the common defense and promoting the general

welfare, remain entrusted to government action or subjected to government oversight.[62]

The private market is also not good at allocating resources to invest in basic science and fundamental research, which can produce breakthroughs and transformational improvements to our lives and our prosperity, but whose "payback period" can take a decade or even decades. It is impossible to imagine what real-life products might evolve from fundamental research, and the prospects for payback are too uncertain in terms of source and too distant in time to attract significant private capital investment.

That is why the federal government historically has played a pivotal role in driving innovation by supporting fundamental research.[63] In the National Academy of Sciences study *Rising Above the Gathering Storm,* a group of eminent leaders drawn from industry, government, and academia offered a wide-ranging set of policy recommendations: promoting education from kindergarten through graduate school in math, science, and technology; assuring that we continue to enrich our population by attracting the best and brightest from around the world; supporting basic research; and assuring that our institutions and laws encourage and reward innovation.[64]

In the twenty-first century, as America's military advantage and economic competitiveness derives increasingly from our innovation and technological prowess, the role of government investment in fundamental research will remain pivotal.

The DOE has been a linchpin of American efforts to support fundamental research. With an annual budget of over $5 billion per year, the DOE's Office

62 See Anadon, Bunn, Narayanamurti, *Transforming U.S. Energy Innovation,* for a more comprehensive discussion of the market failures in energy innovation, and the need for a government role. (esp. pp. 12-25). http://www.cambridge.org/catalogue/catalogue.asp?isbn=1316056643

63 In this report, the term "fundamental" or "basic" research are used interchangeably. They refer to research driven by curiosity in order to expand knowledge rather than by a desire to generate commercial value, whereas "applied" research seeks to solve practical problems and improve the human condition. http://www.sjsu.edu/people/fred.prochaska/courses/ScWk170/s0/Basic-vs.-Applied-Research.pdf.
Some, however, believe this distinction is destructive, since thinking about and trying to solve practical problems can drive fundamental discoveries, such as the transistor, whose first application was demonstrated from the outset. Narayanamurti and Odumosu's book, *Cycles of Invention and Discovery: Rethinking the Endless Frontier* http://www.hup.harvard.edu/catalog.php?isbn=9780674967960

64 Committee on Prospering in the Global Economy of the 21st Century and the Committee on Science, Engineering, and Public Policy; National Academy of Sciences; National Academy of Engineering; and the Institute of Medicine, *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Washington, D.C.: The National Academies Press, 2007).

of Science is the single largest supporter of basic research in the physical sciences in the United States. That office has a storied history dating back to the Manhattan Project and the Atomic Energy Commission. It has built giant supercomputers, accelerators, cyclotrons, and other user facilities that have supported research by governments, research institutions, universities, industry, and individuals. To date, 115 Nobel Laureates have been associated with DOE facilities, dating back to the dawn of the atomic age. They include such scientific giants as Harold Urey, Ernest O. Lawrence, Enrico Fermi, I. I. Rabi, and Glenn Seaborg. The DOE national laboratories in many ways represent the jewel in the crown of American science.

Investments in both basic and applied research have already transformed America's energy economy. Indeed, in one unexpected way, U.S.-government-sponsored investment has already made a significant contribution to putting the United States on track to achieve its goal of reducing greenhouse gas emissions by 26–28 percent compared to 2005 levels by 2025.[65] Between 1978 and 1992, when natural gas prices were declining, the DOE invested around $195 million in shale gas and coal-bed methane reservoir characterization and basic science. Then the Gas Research Institute implemented industry-led technology roadmaps, while federal tax credits encouraged the drilling of wells. And the ingenuity and determination of natural gas pioneer George Mitchell established the viability of fracking while others thought he was just wasting his time and money.[66] Pulitzer Prize-winning historian Dan Yergin called fracking "the most important energy innovation so far of the 21st century."[67]

The combination of those early investments helped lay the groundwork for the shale gas revolution, which brought an enormous energy windfall to all Americans, as shale gas increased from 5 to 56 percent of total U.S. dry natural gas production from 2004 to 2015. Total annual U.S. dry natural gas production rose from 19 to 27 trillion cubic feet from 2000 to 2015, as natural gas prices fell so low that gas-fired power plants displaced coal-fired plants all across the

65 The White House, "FACT SHEET: U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation," November 11, 2014, https://www.whitehouse.gov/the-press-office/2014/11/11/fact-sheet-us-china-joint-announcement-climate-change-and-clean-energy-c.

66 MIT, *The Future of Natural Gas*, June 2011, p. 163. The DOE investments included $15.7 million for coal-bed methane (1978–1982) and $179.5 million for gas shales (1978–1992), http://energy.mit.edu/wp-content/uploads/2011/06/MITEI-The-Future-of-Natural-Gas.pdf. *See also* Daniel Yergin, *The Quest: Energy, Security, and the Remaking of the Modern World* (Penguin, 2012).

67 *America's Energy Security and Innovation: Hearing Before the Subcommittee on Energy and Power of the House Energy and Commerce Committee*, 113th Congress, February 5, 2013 (statement of Daniel Yergin), http://docs.house.gov/meetings/IF/IF03/20130205/100220/HHRG-113-IF03-Wstate-YerginD-20130205.pdf.

United States.[68] Since natural gas emits just half as much carbon as coal, the fracking revolution helped drive down U.S. CO_2-equivalent emissions by 9 percent from 2005 to 2013.

The transportation sector still absorbs vast amounts of energy and accounts for 20 percent of U.S. greenhouse gas emissions.[69] Fuel-guzzling long-haul trucks add over 400 million tons of CO_2 to the atmosphere each year. But Oak Ridge National Laboratory, teaming with the National Aeronautics and Space Administration (NASA) and private industry scientists and using its powerful "Jaguar" Cray supercomputer to perform computational fluid dynamics, analyzed the shape of every bolt, seam, and edge on these big rigs with a view to maximizing efficiency.[70] They developed an entire under-chassis tray to create an aerodynamic profile around the wheels and axles, cutting drag and allowing the wind to slipstream around the whole assembly. It may not make an eighteen-wheeler look as sleek as an Aston Martin, but the results are solid: a six-percent increase in fuel efficiency. Given that long-haul trucking accounts for almost 15 percent of oil consumption in the United States, that equates to taking 2.4 million cars off the road each year.[71]

Continued investment in science and technology will be pivotal to building our clean energy future. One of the most exciting innovations in recent years was the establishment of an organization called the Advanced Research Projects Agency for Energy, or ARPA-E.[72] The organization was authorized by Congress during the administration of George W. Bush, but first funded under President Obama, and it was strongly championed by Nobel Laureate and Secretary of Energy Steven Chu.

ARPA-E is chartered to support potentially transformational energy ideas, with a view to bringing a wide variety to the point where the private sector might step in and invest in subsequent stages in the development of a new technologies or innovations. More than four hundred projects have been

68 U.S. Energy Information Administration, "U.S. Dry Natural Gas Production," May 31, 2016, https://www.eia.gov/dnav/ng/hist/n9070us2A.htm.

69 "Source of Greenhouse Gas Emissions," U.S. Environmental Protection Agency, May 26, 2016, https://www3.epa.gov/climatechange/ghgemissions/sources/transportation.html.

70 One petaflop represents a computer's ability to perform one quadrillion floating point operations per second (FLOPS). One petaflop equals a thousand teraflops.

71 Calculated by using statistics from energy.gov, applying a 6% reduction in heavy trucking fuel usage to the approximately 2.8 million barrels per day of oil equivalent consumed by heavy trucking (based on 2013 data) to find a 62 million barrel per year savings. Assuming an average per car consumptions 498 gallons, or roughly 26 barrels of oil equivalent, produces the 2.4 million car-equivalent result cited above.

72 *Rising Above the Gathering Storm*, pp. 152–158.

funded. One measure of the program's success is its ability to attract private capital; as of 2015 some $135 million investment in thirty-four ARPA-E projects has attracted more than $850 million in private-sector follow-on funding. Moreover, over thirty ARPA-E project teams have formed new companies to advance their technologies, and more than three dozen projects have partnered with other government agencies.[73]

ARPA-E captured the imagination of America's energy innovators. Its annual conference quickly became *the* go-to event for energy innovators and for networking among scientists, engineers, entrepreneurs, and government officials. Keynoters have included former President Bill Clinton, Bill Gates, and Elon Musk. The energy projects funded have ranged from the nearly practical (improved pumps and tanks for compressed natural gas cars) to the nearly visionary (intermediate density fusion).

The Obama Administration launched two other new DOE programs to promote science and innovation. In contrast to the "venture capital" model that drives ARPA-E, which uses grants ranging from less than $1 million to several million dollars to attract private investors to select transformational technologies and bring them to market (think Steve Jobs and Steve Wozniak), more than forty Energy Frontier Research Centers (EFRCs) gave smaller grants to teams of investigators (think James Watson and Francis Crick) working on solving "Grand Challenges" in fundamental research problems that could help transform the U.S. energy economy. These challenges were selected from the major roadblocks to progress in clean energy at a 2012 workshop, which bought together experts from industry, academia, and state and local governments.

The workshop identified five major challenges for basic energy sciences that were scientifically deep, clear, and well-defined, and which promised dividends that would improve the U.S. economy and energy leadership.[74] The challenges are focused on trying to make a leap in the "understanding and control of matter, energy, and information at a molecular and atomic level."

73 Advanced Research Projects Research Agency-Energy, "Overview," last modified April 12, 2016, http://arpa-e.energy.gov/sites/default/files/ARPA-E_FactSheet_041216.pdf.

74 The full list of Grand Challenges can be found on http://science.energy.gov/bes/efrc/research/grand-challenges/. See also http://science.energy.gov/~/media/bes/pdf/reports/files/Directing_Matter_and_Energy_rpt.pdf.

These Grand Challenges set out ambitious goals in the hope that the United States becomes energy secure and environmentally sustainable by accelerating scientifically risky research that might otherwise not be completed. The EFRCs are integrated, multi-level partnerships among universities, research labs, national laboratories, and private sector firms that are funded at $2 to $4 million per year for five-years at a stretch.[75] Dozens of them across thirty-four states are working to support the DOE's mission and work on these challenges, supporting approximately 1600 students and fellows across 110 institutions are involved in these centers.

To tackle complex, interdisciplinary, industrial scale challenges, the DOE obtained authority under the Recovery Act to launch a number of "Energy Innovation Hubs," each of which brings together a number of institutions (including national laboratories, universities, and industries) "that combine basic and applied research with engineering to accelerate scientific discovery that addresses critical energy issues" (think Bell Labs or the Manhattan Project). At present four hubs exist, working on light-water reactor simulation, artificial photosynthesis, critical materials, and energy storage, with each budgeted to receive between $75 million and $125 million over five years.[76] It is still too early to say whether the hubs will live up to their aspirations, and one hub has been closed, so their performance needs to be reviewed before we can judge whether it makes sense to extend funding for the existing hubs or to add new ones.

Earlier, in 2007 the DOE established three Bioenergy Research Centers aimed at solving the fundamental challenge posed in breaking down the tough cellulosic content of biomass materials such a wood, switch-grasses, corn stover, and other crop residues, and synthesizing it into fuels that can compete with fossil fuels. The idea is to shift to a form of biofuels that does not pose the problems associated with the current generation of ethanol-based fuels made from corn. Those problems include competing for scarce food resources and creating biofuels that end up adding rather than subtracting carbon from the atmosphere after factoring in the CO_2 generated by the tractors, ploughs, threshers, and other equipment used to cultivate and harvest corn.

75 An overview of current EFRCs are available here: http://science.energy.gov/~/media/bes/efrc/pdf/overviews/ALL_EFRC_Overviews.pdf.

76 Congress funded the Joint Center for Artificial Photosynthesis at $15 million per year; the rest were funded at approximately $25 million per year; *Department of Energy Oversight: Energy Innovation Hubs*, House Subcommittee on Energy, Committee on Science, Space, and Technology, June 17, 2015. https://www.gpo.gov/fdsys/pkg/CHRG-114hhrg97565/pdf/CHRG-114hhrg97565.pdf.

While these programs have yet to produce breakthrough results, they represent the kind of public investment in long-term scientific and technological challenges that can pay off over time. It will be important to monitor the work of these programs carefully, and to be prepared to make adjustments as soon as the evidence supports doing so. There is no fault in trying out many new ideas, most of which may turn out to be unworkable. Indeed, there is virtue in bold experimentation and imagination. The fault comes in persisting in a path once it is shown to lead into a cul de sac. Part of the genius of American science is to fail often, but fail quickly, and then move on to the next idea.

If government investments must focus on the highest priorities, where scientific breakthrough is required, then energy storage and carbon capture and sequestration (CCS) should rise to the top. Energy storage must be a top priority because wind and solar energy sources can never provide baseload power until their utilization is detached from the intermittent nature of wind and solar power.[77] Breakthroughs in CCS are important because, despite all the changes in other sources of power generation, coal will remain an important source of electricity at a large scale in such demand-growth markets as India, Indonesia, and China. If coal will continue to be burned in any event, it is strongly in our interest to develop and deploy cost-effective CCS at scale.[78]

Recommendation 4: **Invest in basic research and long-term development.**

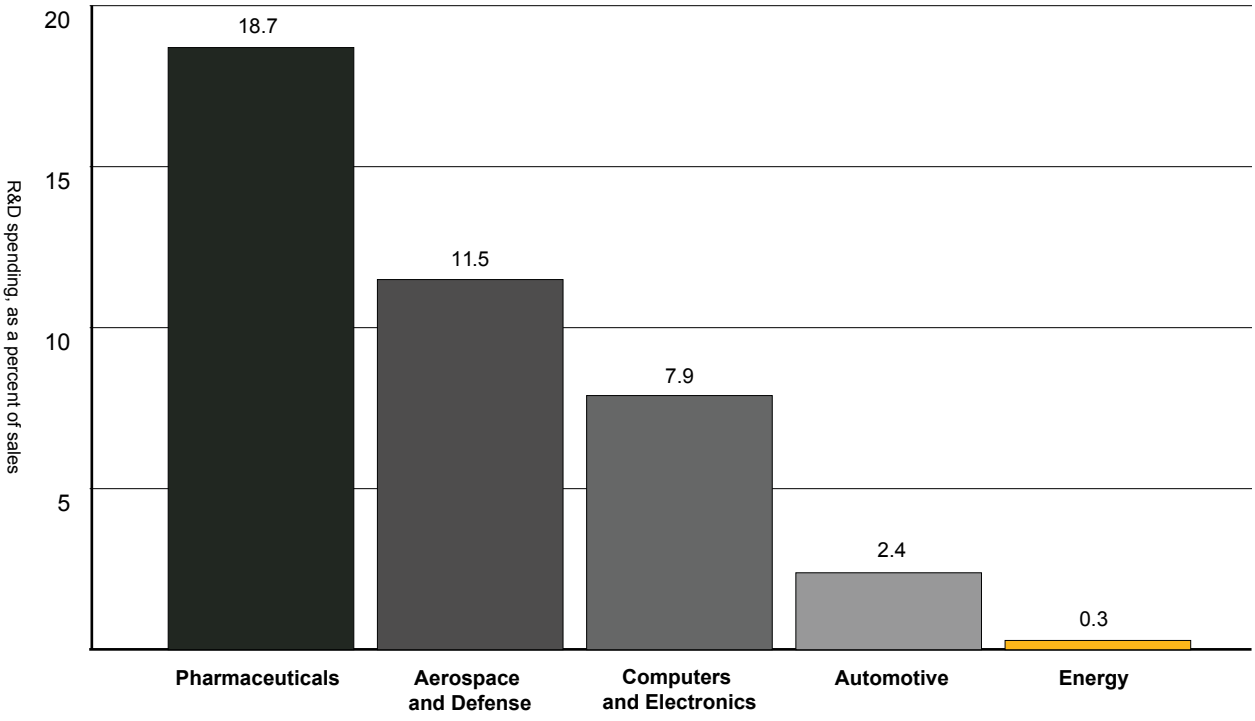
Government funding of basic research has been and should remain a pillar of our nation's scientific effort, both in general and with regard to laying the foundations for our energy future. In recent years a number of eminent groups of American business and scientific leaders, as well as leading international voices such as the International Energy Agency and the Intergovernmental Panel on Climate Change (IPCC), have called for major increases in U.S. government investment in energy research and development (R&D). Noting the importance of innovation in driving American economic leadership and the

77 For a contrary view, see Hossein Safaei and David W. Keith, 'How much bulk energy storage is needed to decarbonize electricity?" http://pubs.rsc.org/en/content/articlehtml/2015/ee/c5ee01452b

78 The DOE received $3.4 billion under the American Reinvestment and Recovery Act for a series of projects that include coal power projects, carbon capture from industrial projects, and a series of regional carbon sequestration partnerships to characterize geologic formations for their suitability to sequester CO2.

particular difficulties in raising private investment dollars for new power-generation technologies that require massive investments, and which may take much longer to develop and deploy than most funds are prepared to wait for a return on their investments, The American Energy Innovation Council urged the U.S. government to increase annual investment in energy innovation from $5 billion to $16 billion.[79] To give some sense of proportion, consider that, as a percentage of sales, the energy industry invests less than .5 percent on innovation, far less than the automotive, computers and electronics, aerospace, defense, and pharmaceutical industries.

Industry R&D spending as a percent of sales



That basic governmental investment forms a critical foundation, but only one part, of an overall investment strategy. Given the scale of energy infrastructure in our economy, and the share of it held in private hands, government funding will never be enough to reshape our energy future on its own. Nor should it be. There are, after all, profits to be made, opportunities to exploit, and markets to develop, where private capital may be able to benefit from long-term investments. And in an age where more and more income is being concentrated in an increasingly small fraction of the populace, it turns out that some of that small fraction has both the will and the means to make a difference.

79 American Energy Innovation Council, Bipartisan Policy Center, *Restoring American Energy Innovation Leadership: Report Card, Challenges, and Opportunities*, February 2015, http://bipartisanpolicy.org/wp-content/uploads/2015/02/AEIC_Energy_Innovation.pdf.

That is why Bill Gates's announcement of the Breakthrough Energy Coalition in the run-up to the 2015 Paris Climate Change Conference was so important. Gates assembled a private, international group of twenty-eight investors that will provide venture capital for early stage companies developing clean energy technologies, especially those that can increase energy access. The group—which includes such eminent investors and business leaders as Jeff Bezos, Ray Dalio, John Doerr, Vinod Khosla, Jack Ma, Ratan Tata, and Meg Whitman—aims to use its financial strength to make investments that smaller investors would likely pass on in light of the risks inherent in research and the long time horizons for return on investment.

In parallel with the Gates's announcement, President Obama announced Mission Innovation, an initiative to accelerate public and private global clean energy innovation to address global climate change, provide affordable access to clean energy for consumers in the developing world, and help create commercial opportunities in clean energy. Through the initiative, twenty countries (including the five most populous nations—China, India, the U.S., Indonesia, and Brazil) committed to doubling their respective clean energy R&D investment over five years.

A year later, Gates announced the launch of a $1 billion clean-technology fund, Breakthrough Energy Ventures, that will invest in companies developing low-cost, low-carbon technologies, including those related to power generation and storage, transportation, industrial applications, agriculture and energy system efficiency.[80] Its investments would take place over the next 20 years.

Together, Mission Innovation and the Breakthrough Energy Coalition represent a fresh opportunity to drive fundamental research across a broad array of technologies to move the needle toward a lower-carbon future.[81] Given the $13.5 trillion in efficiency measures and low-carbon technologies that the IEA estimates is required by 2030 in order to carry out the 187 national climate pledges made in connection with the Paris Climate Agreement, there is no time to waste.

80 Cassandra Sweet, "Bill Gates, Others Launch Clean Energy Fund", *Wall Street Journal* (December 12, 2016), https://www.wsj.com/articles/bill-gates-others-launch-clean-energy-fund-1481577280

81 The White House, "Fact Sheet: Mission Innovation," November 29, 2015, https://www.whitehouse.gov/the-press-office/2015/11/29/fact-sheet-mission-innovation.

5. Hang together or hang separately: the road to Paris

The United States —though home just over 4 percent of the world's population—accounts for roughly one-quarter of global energy consumption, one-fifth of global electricity generation, and one-seventh of global greenhouse gas emissions.[82] So U.S. action, or inaction, will continue to have a major impact on the future of greenhouse gas emissions worldwide.

But equally clearly, U.S. action alone cannot adequately address the climate challenge. Even if the United States stopped emitting any carbon overnight, the effect on global efforts to head off the effects of climate change would be limited, given that three-quarters of greenhouse gas emissions arise elsewhere. Indeed, the Group of Major Economies Forum (whose membership broadly overlaps with the Group of 20) together account for over 80 percent of the world's GDP, energy consumption, and energy-related CO_2 emissions. Since the world's atmosphere—and all the chemicals and particulates within it—knows no international boundaries, only action at a global scale can be effective.

Acknowledging that reality, over the years governments have adopted a series of commitments to address the problem. The Rio Earth Summit of 1992 produced the UN Framework Convention on Climate Change, which entered into force two years later and was further extended by the Kyoto Protocol of 1997. While these treaties raised global consciousness and provided a forum for scientific and diplomatic effort, their practical effects have been limited.

The fundamental challenge in achieving concrete action has been political. Since the United States and Europe have historically used the most energy per capita and emitted the most carbon, for years other nations insisted that, as a matter of fairness, the historic emitters undertake greater and more binding commitments to curtail emissions than those whose economies developed later. Europe accepted this argument, which was codified in the Kyoto Protocol. The U.S. Senate did not, objecting on the grounds that one-sided

82 U.S. Energy Information Administration, "What Is the United States' Share of World Energy Consumption?" last updated May 6, 2016, http://www.eia.gov/tools/faqs/faq.cfm?id=87&t=1; World Resources Institute, *CAIT Climate Data Explorer*, accessed June 9, 2016, http://cait.wri.org/historical/Country%20GHG%20Emissions?indicator[]=Total%20GHG%20Emissions%20Excluding%20Land-Use%20Change%20and%20Forestry&indicator[]=Total%20GHG%20Emissions%20Including%20Land-Use%20Change%20and%20Forestry&year[]=2012&sortIdx=NaN&chartType=geo.

international agreements, which did not require developing countries to make their fair share of emission reductions, "would seriously harm the economy of the U.S." A resolution to that effect passed the Senate 95–0 in 1997.[83]

Thus, even though the Clinton administration signed the Kyoto Protocol, the treaty was never submitted to the Senate for ratification. Without U.S. participation, the practical benefits driven by the protocol were inherently limited.

In the years that followed, China surpassed the United States as the world's leading carbon emitter. From 2000 to 2012 China's CO_2 emissions surged from 3.6 GT to 9.3 GT per year.[84] Over that same time, U.S. emissions fell from 5.7 GT to 5.1 GT per year, while India's doubled from 1 GT to 2 GT per year. While India still trails China and the United States as a distant third, its CO_2 emissions will climb as its population grows by 300 million over the next two decades.[85] (The data on *per capita* CO_2 emissions, however, tell a different story, with the United States at 4.54 metric tons still far outpacing China at 1.8 metric tons and India at 0.46 metric tons.[86])

In its scale and importance in the climate equation, China now stands alone. It accounts for 19 percent of world energy consumption and 23 percent of world carbon emissions, reflecting its dramatic economic growth over the last 15 years.[87] Much of that demand is driven by two giant demographic shifts: the total Chinese population is slated to rise to 1.45 billion by 2040 (then peak and level off), and 100 million people are projected to move from rural areas to cities in the next five years.[88] By 2025 China will have more than 221 cities of one

83 Senate Resolution 98, "A Resolution expressing the sense of the Senate regarding the conditions for the United States becoming a signatory to any international agreement on greenhouse gas emissions under the United Nations Framework Convention on Climate Change," 105th Congress, July 25, 1997,

84 World Resources Institute, CAIT Climate Data Explorer, "CO_2 Emissions Totals—Total CO_2 Emissions Excluding Land-Use Change and Forestry—2000 (Mt CO_2)," accessed June 9, 2016, http://cait.wri.org/historical/Country%20GHG%20Emissions?indicator[]=Total%20CO2%20Emissions%20Excluding%20Land-Use%20Change%20and%20Forestry&year[]=2000&year[]=2012&country[]=United%20States&country[]=China&country[]=India&sortIdx=NaN&chartType=geo.

85 Ibid.

86 Tom Boden, Bob Andres, and Gregg Marland, "Ranking of the World's Countries by 2011 Per Capita Fossil-Fuel CO_2 Emission Rates," Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center, accessed June 9, 2016, http://cdiac.ornl.gov/trends/emis/top2011.cap. National per capita estimates (CO_2_CAP) are expressed in metric tons of carbon (not CO_2).

87 International Energy Agency, *Key World Energy Statistics 2015* (2015): 50, http://www.iea.org/publications/freepublications/publication/KeyWorld_Statistics_2015.pdf.

88 United Nations, Department of Economic and Social Affairs, Population Division, *World Population Prospects: The 2015 Revision* 1: Comprehensive Tables (2015): xxii, https://esa.un.org/unpd/wpp/Publications/Files/WPP2015_Volume-I_Comprehensive-Tables.pdf; "FACTBOX: China's Urbanization Plan 2014–2020," *Xinhua*, March 17, 2014, http://news.xinhuanet.com/english/china/2014-03/17/c_133192830.htm.

million inhabitants or more, compared to just nine in the United States.[89] The resulting economic expansion, fueled largely by coal, is expected to continue, although the pace will vary along with the performance of the Chinese economy.

Given the overall weight of the United States and China in driving global carbon emissions, no matter who should take moral, legal, and financial responsibility for mitigating and adapting to climate change, it is a matter of simple arithmetic to say that *both* China and the United States *must* act forcefully if we want to be serious about limiting carbon emissions. The same is true for much of Asia, the Middle East, and Africa, where energy use and carbon emissions continue to rise steeply even as both are flattening out in the OECD nations. In Southeast Asia alone, even as carbon intensity is expected to improve significantly, energy-related CO_2 emissions are projected to almost double by 2035, reaching 2.3 GT (or slightly less than India's current emissions).[90]

In recent years governments increasingly sidestepped the moral debate and opted into a number of international efforts to promote clean energy, through new and existing organizations, through ministerials and other conferences, through summits and initiatives. Though overall it is unclear how much of a dent these "coalitions of the willing" can make in the world carbon curve, they certainly helped pave the road to Paris.[91]

89 This extraordinary rate of urbanization leads to both unique challenges and options for China's central planners. Of all the levers they can pull, the most effective might come as a surprise: ramping up energy efficiencies in Chinese buildings. China has become a juggernaut of construction on the world stage, and buildings account for about one-quarter of China's energy consumption and carbon emissions. In the three years between 2011 and 2013, China consumed more cement than the United States did in the entire 20th century. In 2012 nearly two-thirds of the world's large construction cranes were found in China. China finishes thirty-two thousand square meters of construction each year, around one-tenth of the total U.S. housing stock. Increasing energy efficiency in buildings by updating and enforcing standards is the easiest and cheapest way for China to cut energy demand and emissions.

90 International Energy Agency, *2013 World Energy Outlook Special Report on Southeast Asia* (September 2013), https://www.iea.org/publications/freepublications/publication/SoutheastAsiaEnergyOutlook_WEO2013SpecialReport.pdf.

91 Ingrid Barsnley and Sun-Joo Ahn, International Energy Agency, *Mapping Multilateral Collaboration on Low-Carbon Energy Technologies* (November 2014). https://www.iea.org/publications/insights/insightpublications/MappingMultilateralCollaboration_FINAL.pdf.

Recommendation 5:
Strengthen international cooperation.

As the web of international cooperation continued to strengthen, so did the drumbeat for more concentrated action. Every year, the Conference of Parties (COP) under the UNFCCC would meet, exchange information, warn the world of impending dangers, and try to build consensus toward more effective international action. Recognizing the mounting body of evidence pointing toward the human origins of climate change, the expanding impacts of the change already experienced, and the rising dangers for catastrophic effects absent a major change of direction, each COP called for stronger measures. By 2011, 17th Conference of the Parties (COP17), in Durban, South Africa, called for the negotiation of a protocol "with legal force" by 2015 for the period beyond 2020, aimed at raising national and international action to reduce greenhouse gas emissions.

The road to Paris was long and arduous process of planning and negotiations involving governments, industry, think-tanks, grass-roots organizations, academia, organized labor, scientists, engineers, and nongovernmental organizations.

As the clock ticked down to Paris, one by one, the parties began to communicate their Intended Nationally Determined Contributions (INDCs) to the greenhouse gas reductions called for under the Convention. The aggregate impact projected for all submitted INDCs would serve as a leading indicator of how close Paris could come to codifying a meaningful global commitment to cut carbon emissions. That is why the decision announced at the U.S.-China Beijing summit in November 2014, which committed the two leading carbon emitters in the world to do more to curb greenhouse gas emissions, was so important. President Obama pledged to cut U.S. emissions by up to 28 percent by 2025, and President Xi Jinping pledged to cap China's greenhouse gas emissions by no later than 2030.[92]

Though they were purely voluntary pledges lacking the force of law, these commitments demonstrated leadership by example from the world's two biggest emitters. It helped that the contributions were widely seen as both

92 White House, "FACT SHEET: U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation," November 11, 2014, https://www.whitehouse.gov/the-press-office/2014/11/11/fact-sheet-us-china-joint-announcement-climate-change-and-clean-energy-c.

achievable and of significant impact. And in September 2015, President Xi and President Obama doubled down on their commitments, announcing a strategy for the Paris Climate Change Conference and a carbon cap-and-trade system in China's industrial sector.[93]

Thus, in addition to helping each country get its own domestic house in order, the U.S.-China climate partnership galvanized cooperation by other large emitters, including India and Brazil. In all, 187 countries submitted plans to curb emissions in connection with the December 2015 Paris Climate Change Conference (also called COP21).

Adding a useful measure of industry support, ten leading international oil companies, including BP, Royal Dutch Shell, Saudi Aramco, Pemex and Total, announced in October 2015 that they would improve the energy efficiencies of their businesses while partnering with the UN, other multilateral corporations, nation states, and civil society to reach the 2˚C goal.[94] In doing so, the companies stressed the need for governments to agree to a framework that set the international climate agenda for both businesses and countries. While none of the U.S. oil majors joined this initiative, it was philosophically consistent with the conclusion the U.S. executives had endorsed in the 2011 National Petroleum Council study cited earlier.[95]

Unexpected tragedy also made a difference. On November 13 terrorists carried out a series of suicide bombings and shootings at restaurants and concert halls in Paris, killing 130 people and wounding 368 more. In a show of solidarity, President Obama and other world leaders reaffirmed their commitment to go to Paris for the COP21 proceedings, adding momentum to the effort to reach a final deal.

At the end of the day, they did. The deal was far from perfect. Its commitments were not legally binding and it included no enforcement mechanism. And if all the nations' commitments to curb emissions were faithfully and completely implemented, the world would still miss its targets for limiting

93 The White House, "FACT SHEET: The United States and China Issue Joint Presidential Statement on Climate Change with New Domestic Policy Commitments and a Common Vision for an Ambitious Global Climate Agreement in Paris," September 25, 2015, https://www.whitehouse.gov/the-press-office/2015/09/25/fact-sheet-united-states-and-china-issue-joint-presidential-statement.

94 Oil and Gas Climate Initiative, "Joint Collaborative Declaration," October 16, 2015, http://www.oilandgasclimateinitiative.com/~/media/Files/O/Ogci/documents/ogci-ceo-Declaration-2015.pdf

95 National Petroleum Council, *Prudent Development: Realizing the Potential of North America's Abundant Oil and Gas Resources* (2011), http://www.npc.org/reports/NARD-ExecSummVol.pdf.

global warming by a mile. (More on that shortly.) That said, the Paris agreement did mark significant progress in the campaign to fight irreversible climate change. It set 2˚C as its goal for temperature change before 2100, and agreed to pursue efforts to limit change even more sharply, to 1.5˚C. The agreement moved beyond the old debates over which countries had more or less responsibility to take action, instead embracing the 187 national goals to cut greenhouse gases. It provided for enhanced transparency measures, and called for five-year reporting cycles on progress made. And, if fifty-five nations, representing 55 percent of global emissions, ratified the accord, it would enter into force. By autumn 2016 both criteria had been met, so the accord entered into force on November 4, 2016.

From right, French President Francois Hollande, French Foreign Minister and president of the COP21 Laurent Fabius, United Nations climate chief Christiana Figueres, and United Nations Secretary General Ban Ki-Moon applaud after the final conference at the COP21, the United Nations conference on climate change, December 12, 2015. (AP Photo/Francois Mori)

Paris should be viewed not as an end in itself, but rather as another milestone on the road to a cleaner future. To realize its promise, vigorous implementation by all participating governments and their private sectors will be essential, as will continued monitoring and support of the other stakeholders to hold leaders accountable for the implementation. The example that the United States sets will be crucial in this regard. That is why so much attention is focused on President Trump's upcoming decision, expected in May, regarding how to proceed with respect to the Paris Agreement.[96]

96 See https://www.theguardian.com/us-news/2016/nov/13/trump-looking-at-quickest-way-to-quit-paris-climate-agreement-says-report. While technically the U.S. can't officially withdraw for four years, for all practical purposes, it could ignore it, http://www.vox.com/2016/11/9/13571318/donald-trump-disaster-climate.

Part II: Back to the (nuclear) future

So for anyone who *does* worry about climate change, Paris just isn't enough. *Even if every signatory meets 100 percent of its own announced goals for carbon limitations, the world will not even come close to meeting its goal of limiting warming to 2°C over pre-industrial levels.* On the contrary, a number of studies have concluded in this case that the world would substantially overshoot this goal.[97] Of course, there are different assumptions, uncertainties, and ranges among these studies, which have been carried out by a number of entities, including the International Energy Agency, the European Commission Joint Research Centre, the London School of Economics, the Massachusetts Institute of Technology, and the UN Environment Program. But none project a better result from INDC implementation than 2.7°C, while the most pessimistic (the MIT high case) shows a 5.2°C outcome.

6. Nuclear energy: once more into the breach

So even if the Paris Agreement were fully and timely implemented—a heroic if not delusional assumption—it would not come close to meeting its own target. Adding all the commitments to wind, solar, geothermal, hydropower, and biofuels in the mix would not do it. Subtracting all the demand that can be saved if we double down on energy efficiency investments would not do it. Expanding "carbon sinks" in the Amazon through ambitious reforestation programs—where replanted trees absorb the overflowing CO_2 from the atmosphere—would not do it. All of these measures put together would not do it.

This logic brings us back, once again, to the potential role of nuclear power: the most concentrated source of carbon-free electrons that has yet been developed. The argument to expand nuclear power to curtail CO_2 emissions is clear.

97 United Nations Framework Convention on Climate Change, "Global Response to Climate Change Keeps Door Open to 2 Degree C Temperature Limit," October 30, 2015, http://newsroom.unfccc.int/unfccc-newsroom/indc-synthesis-report-press-release/.

But are we institutionally capable of expanding nuclear power without unacceptably expanding nuclear risks? That had been the premise of Eisenhower's Atoms for Peace approach. Didn't the 1974 Indian nuclear test and subsequent attempts to obtain sensitive nuclear fuel cycle facilities under the guise of "peaceful nuclear cooperation" undermine that premise?

The answer is that the *original* Atoms for Peace premise had indeed been shattered, but much has been done since 1974 to repair the damage and to build new structures to constrain the threat. For a quarter of a century the United States imposed sanctions on India and Pakistan in response to their covert nuclear explosive programs. Beginning in the mid-1970s, concerted multilateral diplomacy stopped countries from purchasing turnkey uranium enrichment and plutonium reprocessing facilities, and led to establishment of a Nuclear Suppliers Group that promulgated guidelines to strengthen export controls over both nuclear and dual-use technology.[98]

Several additional measures have been adopted to raise the barriers against the diversion of peaceful nuclear assistance to explosive purposes. A number of countries promulgated "catch-all" export controls to permit authorities to seize proliferation-related items found in transit from one place to another, even in the absence of a specific export control governing the export of the item being shipped. And, as noted above, additional initiatives—UN Security Council Resolution 1540, the Global Initiative to Combat Nuclear Terror, and many others—strengthened international efforts to prevent the proliferation of nuclear weapons, materials, and technology.

We must continue to do all we can to prevent any leakage of dangerous technologies, equipment, or materials from civilian to military purposes.[99] For this purpose, it is useful to maximize awareness and support for physical security from the network of stakeholders who have invested heavily in nuclear energy and therefore have a lot to lose should anything happen to undermine the viability of nuclear energy. While the diversion and misuse of nuclear materials and nuclear technology would harm society as a whole, the nuclear industry is better positioned than the general populace to muster the resources and target

98 Founded in 1974, the Nuclear Suppliers Group (NSG) is a group of forty-eight nuclear-supplier countries that seeks to contribute to the nonproliferation of nuclear weapons through the implementation of two sets of guidelines for nuclear exports and nuclear-related exports.

99 See William Potter, Leonard Spector, Martin Malin, and Matthew Bunn, *Preventing Black-Market Trade in Nuclear Technology* (Cambridge University Press, forthcoming) on all the various aspects, from export controls to intelligence to interdiction, of stopping these kinds of illicit flows.

them appropriately to make a material difference in enhancing nuclear safety and security.

So the over-optimistic, if not naïve, premise of the original Atoms for Peace approach has been abandoned. Instead of assuming that satisfying a government's peaceful nuclear aspirations would remove any thought by that government of possibly pursuing a military nuclear option, governments now emphasize restraint and vigilance in controlling nuclear technology, material, and equipment.

The United States and other nuclear suppliers are well placed to pursue a stronger, more resilient version of the earlier Atoms for Peace concept. The international community has learned and applied the lessons of the Indian 1974 test and the A. Q. Khan-driven black market in uranium enrichment technology.[100] Nuclear export controls have been tightened, including through the development of controls over dual-use technologies and those related to enrichment and reprocessing by the Nuclear Suppliers Group. International Atomic Energy Agency (IAEA) safeguards were strengthened through the promulgation of an "Additional Protocol" after the cases of Iraq and North Korea underscored that the IAEA was not in a strong position to detect undisclosed nuclear activities of concern. The Additional Protocol included a number of measures, including increased reporting requirements from member states and access to undeclared sites by IAEA inspectors.[101] And President Obama launched a series of Nuclear Security Summits that increased international cooperation on reducing the nuclear threat and the dangerous materials and technologies that enable it, including through minimizing the use of highly-enriched uranium, strengthening security at nuclear facilities, instituting steps to detect and interdict illegal trafficking in nuclear materials, and more.

At the same time, we must recognize that the technological barriers to designing and building nuclear weapons continue to diminish each year. That means that more of our efforts to combat nuclear weapons proliferation must be dedicated either to reducing the demand for such weapons (as historically has been done through the protection that the U.S. nuclear umbrella provides to

100 See Daniel Poneman, *American Nuclear Diplomacy: Forging a New Consensus to Fight Climate Change and Weapons Proliferation*, Belfer Center for Science and International Affairs, August 2016, http://www.belfercenter.org/sites/default/files/legacy/files/American%20Nuclear%20Diplomacy.pdf

101 International Atomic Energy Agency, "Additional Protocol," last updated May 24, 2016,,https://www.iaea.org/safeguards/safeguards-legal-framework/additional-protocol.

our NATO and Asian allies) or to targeted efforts to prevent those who seek such weapons from achieving their aims.

In addition, if nuclear power is to play a role in fighting climate change while minimizing proliferation risks, then it behooves us all to see the nuclear industry be strong, not weak, with a well-funded and well-trained focus and culture emphasizing safety and security in all things nuclear.

In that sense, a robust, safe, secure, and well-regulated nuclear enterprise worldwide can help address *both* existential threats. And given the high priority the American nuclear industry places on safety and security, preserving a strong American presence in the global market—particularly at a time when more reactors are being built in more countries—should be a high national priority for *both* environmental and national security reasons.

American nuclear leadership would be important even if the United States did not build any more reactors beyond those now under construction. Why? Because the United States still has the largest fleet of commercial nuclear reactors in the world—nearly one quarter of the nearly 450 reactors operating internationally, providing nearly one-fifth of the U.S. installed power generation base. In addition, the U.S. Navy has 86 nuclear-powered vessels. The United States therefore has a powerful vested interest in nuclear energy being carried out safely and with minimal proliferation risk wherever it is used.[102] If Fukushima brought home one lesson, it is that an accident anywhere is an accident everywhere in terms of undermining public confidence in the safety of nuclear power. One can only imagine that a nuclear terrorist attack involving commercial nuclear power would have a similarly devastating impact on public confidence in nuclear energy.

Without casting aspersions on others, it is fair to say that the U.S. commitment to nuclear safety and nuclear nonproliferation is second to none, and that our laws, regulations, and standards are second to none. But while U.S. leadership once was clear and unquestioned, it has steadily eroded over recent decades. During the 1980s the United States was building more nuclear reactors than any other nation—up to thirty at one time at its peak. Now China, Russia, Korea, and India are building more reactors than we are. Once the United States dominated global nuclear enrichment markets. Now we are hanging on by a thread.

102 World Nuclear Association, "Number of nuclear reactors operable and under construction," http://www.world-nuclear.org/nuclear-basics/global-number-of-nuclear-reactors.aspx.

If the United States is to regain the initiative and, potentially, its leadership, then it should find a way to keep building nuclear reactors, keep spawning nuclear innovation in advanced generation reactors and fuel cycles, keep attracting and training nuclear scientists and engineers, and keep supporting a U.S. industrial base able to meet the demanding specifications required for the safe and secure development of nuclear power.

To be clear, this is *not* a call for pouring billions of federal taxpayer dollars in a conventional government spending program to support nuclear energy. Some investment is warranted for the long-term scientific and national laboratory work that have always been the domain of the U.S. Department of Energy and its national laboratories. Also, billions of dollars in untapped loan guarantee authority could help stimulate investment in nuclear projects by lowering the cost of borrowing for highly capital-intensive nuclear projects without actually spending the money, which only goes out the door if the project defaults on the loan—and historically the default rate on DOE loan guarantees has been low. Still more can be done with public-private partnerships, and a fertile environment for venture capital can already be seen in the area of advanced nuclear technologies. In short, rather than just throwing money at nuclear projects, we need to think in a holistic fashion about a whole series of reforms to the sector that would allow nuclear energy to be developed more efficiently and effectively than can be achieved today.

If that kind of nuclear resurgence can be achieved in the United States, it would greatly strengthen our energy security, as nuclear power's salient feature is its always-on reliable delivery of large amounts of baseload power. It would restore the global leadership in nuclear energy that the United States once enjoyed unchallenged. As the most reliable, prodigious source of carbon-free power currently available to us, nuclear power plays to our strengths—the proven expertise, resources, and skills needed to make it succeed can all be found within our borders.

A reinvigorated nuclear sector would drive job growth and help sustain a vital industrial manufacturing base in the United States. Nuclear plants depend on a large, talented, and skilled workforce to support all phases of the plant's life from design, to construction, to maintenance and operations, and ultimately to retirement. These high-skill jobs employ engineers, welders, electricians, and many other trades that are vital to the growth and stability of the U.S. economy. The approximately one hundred commercial nuclear reactors

currently operating in the United States depend on the contributions of over one hundred thousand workers. Each "nuclear plant requires four hundred to seven hundred direct permanent jobs" that typically "pay 36 percent more than average salaries in the local area."[103] In addition to supporting the nuclear plants in the United States, the nuclear industry can also create jobs through nuclear exports. For example, the AP1000 projects under way in China supported thousands of U.S. jobs.[104]

Hence, the next recommendation:

Recommendation 6: **Accelerate the deployment of nuclear energy.**

We have seen that the case for nuclear energy as a vital element in fighting climate change is straightforward. It can be an enormous source of baseload power, while reactor operations emit zero carbon. In the United States, as noted earlier, nuclear power constitutes just under 20 percent of our installed power generation but provides more than 60 percent of our carbon-free power.

We have seen how the international community has labored for decades to combat climate change, publishing thousands of studies, rallying thousands of nongovernmental organizations with millions of members, negotiating a series of treaties and international agreements, mobilizing trillions of dollars of capital, and convening the parties to the 1992 UNFCCC twenty-one times until they finally hammered out the 2015 Paris Climate Agreement.

So if we are to hedge effectively against the potential consequences of climate change of catastrophic climate change that the international community has agreed is critical to our future, we will need to do more. Much more. How do we close the gap? By truly embracing an all-of-the-above strategy. Enact a carbon emissions tax. Double down on efficiency, level the playing field among

103 Nuclear Energy Institute White Paper. "Nuclear Energy's Economic Benefits: Current and Future," April 2014, http://www.nei.org/Master-Document-Folder/Backgrounders/White-Papers/Nuclear-Energy-s-Economic-Benefits-Current-and-Fut.

104 Mark Holt & Mary Nikitin, Federation of American Scientists, "U.S.-China Nuclear Cooperation Agreement", May 2015, https://fas.org/sgp/crs/row/RL33192.pdf

all low-carbon energy sources, and invest in basic science. Intensify international efforts… and expand nuclear power.

The International Energy Agency (IEA) agrees. After reviewing the available technologies to meet the international climate goals, the IEA concluded, "There is a need to introduce market incentives to favour all low-carbon technologies … and to recognize the vital contribution that nuclear energy can make."[105] Specifically, the IEA projects that nuclear generation should account for 17 percent of global electricity generation by 2050 to meet the IEA's 2°C target. [106] That would require more than doubling the world's nuclear energy capacity over the next twenty years, from 396 gigawatts to 930 gigawatts.[107] Obviously, to meet the Paris Agreement's 1.5°C target would take even more.

The World Nuclear Association (WNA) has developed its own energy vision to meet the IEA's 2°C target—a mixture of low-carbon energy sources that includes 25 percent nuclear energy, or approximately 1000 gigawatts of new capacity by 2050.[108] To meet this goal, the WNA urges that the playing field be leveled for nuclear power by reforming energy market frameworks, harmonizing regulatory processes through global standards and licensing efficiencies, and embracing a safety paradigm that improves "public well-being by reducing emissions" and ensuring high nuclear safety standards.

But the future of nuclear power in the United States is far from clear. On the positive side of the ledger, four new commercial reactors are being built in the United States today and the first new commercial U.S. nuclear power plant of the 21st Century has entered into service.[109] On the other hand, these new commercial reactor projects are significantly delayed and over budget, while no new nuclear units are being built in deregulated energy markets in the United States, and none are expected. Indeed, the unfavorable economics for

105 International Energy Agency, *Energy Technology Perspectives 2015* (Paris: OECD Publishing, 2015), http://www.iea.org/bookshop/710-Energy_Technology_Perspectives_2015.

106 Kelly Lavin and Taryn Fransen, "Why Are INDC Studies Reaching Different Temperature Estimates?" World Resources Institute, November 9, 2015, http://www.wri.org/blog/2015/11/insider-why-are-indc-studies-reaching-different-temperature-estimates.

107 International Energy Agency and Nuclear Energy Agency, "Technology Roadmap—Nuclear Energy," January 29, 2015, http://www.iea.org/newsroomandevents/news/2015/january/taking-a-fresh-look-at-the-future-of-nuclear-power.html.

108 World Nuclear Association, "The Harmony Programme," http://www.world-nuclear.org/our-association/what-we-do/the-harmony-programme.aspx.

109 The first of these, Watts Bar 2, being built by the Tennessee Valley Authority, was actually started in 1973, but construction was suspended for 39 years. The reactor went critical in May 2016. The other four—two V. C. Summer units in South Carolina and two Vogtle units in Georgia—are still under construction.

nuclear power in those markets and other factors have led to the closure of five nuclear plants in the last five years (Fort Calhoun, Kewanee, San Onofre, Vermont Yankee, and Crystal River) and the announcement that five more plants will close (the Palisades, Pilgrim, Oyster Creek, and Diablo Canyon sites), while several more nuclear plants stand at risk of early closure.[110]

Last year, however, recognition of the economic and energy losses inherent in the closure of well-operating nuclear power plants with many useful years of service—and the attendant setback to U.S. efforts to cut carbon emissions—helped save a number of nuclear plants from premature closure. In 2016, Exelon—the U.S. utility with the largest nuclear fleet (twenty-two reactors)—announced that it would close its Clinton and Quad Cities nuclear plants in Illinois, which were losing $100 million per year even while offering electricity at less than 4 cents per kilowatt-hour.[111] In Illinois's deregulated energy market, at those prices nuclear power still could not compete with cheap natural gas, especially given the difficulties in getting credit for providing carbon-free power or reliable electricity, even when other power sources cannot. Fortunately, the Illinois legislature passed legislation that extended state subsidies for renewable energy to "zero-emission" energy sources like nuclear power, allowing the Clinton and Quad Cities plant to operate for another decade.[112] And earlier in the year, intensive negotiations involving the State of New York led to the successful sale of the imperiled Fitzpatrick plant from Entergy to Exelon, saving that plant from premature closure.[113]

Forceful state actions and policies will be necessary to sustain the viability of nuclear energy in the United States, but the issue also needs to be addressed at a national level. In May 2016, the DOE held an industry summit on "Improving the Economics of America's Nuclear Power Plants" aimed at addressing the challenge of preserving the existing U.S. nuclear fleet. Surveying the landscape, Nuclear Energy Institute President Marvin Fertel concluded that if measures to redress

110 Frank Witsil, Detroit Free Press, "Palisades Nuclear Power Plant to Close in 2018," December 8, 2016, http://www.freep.com/story/news/local/michigan/2016/12/08/palisades-nuclear-power-plant-closing/95135616/.

111 Steve Daniels, "Exelon Sees Little Hope of Saving Quad Cities Nuke," *Crain's Chicago Business*, July 29, 2015; James Conca, "Illinois Sees the Light—Retains Nuclear Power," *Forbes*, December 4, 2016, http://www.forbes.com/sites/jamesconca/2016/12/04/illinois-sees-the-light-retains-nuclear-power/#2c372c5f16a7. http://www.chicagobusiness.com/article/20150729/NEWS11/150729783/exelon-sees-little-hope-of-saving-quad-cities-nuke.

112 John O'Connor, "Exelon to Close Two Nuclear Plants; Still Seeking Subsidies," *Boston Herald,* June 2, 2016, http://www.bostonherald.com/news/national/2016/06/exelon_to_close_2_nuclear_plants_still_seeking_subsidies

113 "Gov. Cuomo says Fitzpatrick nuclear plant saved: Whole state should be smiling", Syracuse.com, http://www.syracuse.com/news/index.ssf/2016/08/gov_cuomo_says_fitzpatrick_saved_whole_state_should_be_smiling_right_now.html

these problems are not taken, fifteen to twenty more nuclear plants are "at risk of premature shutdown over the next five to ten years."[114] If that nuclear electricity generation were to be replaced by other energy sources, it would in effect increase the CO2 emissions by 87 million metric tons, or nearly 4.3 percent more than the electricity sector's current level.[115] The amount of electricity generation that would be lost by closing these plants would be equal to approximately half of all electricity generated by wind, solar, and other non-hydro renewables in 2015.[116]

What will it take to enable nuclear energy to deliver cost-competitive power to consumers while lowering US carbon emissions in the coming decades? A number of challenges must be overcome, including slowing electricity demand, low natural gas prices, the lack of a price on carbon emissions, high regulatory burdens and uncertainties, subsidized competition from wind and solar, renewable portfolio standards that tilt the low-carbon field away from nuclear, and much more. In addition, nuclear energy will need to satisfy legitimate public concerns about its safety and security, the disposition of nuclear waste, and its economic viability. Let us examine each of these challenges in turn.

9. Safety and security first

Starting from basic principles, when it comes to nuclear power, safety and security must come first. The nuclear industry has no higher priority.

The companion to this report, *American Nuclear Diplomacy,* focused on the fundamental security challenges entailed in harnessing the power of atomic fission for peaceful purposes. It noted the importance of the suite of tools that have been developed to reduce the risk of nuclear terrorism and weapons proliferation, from international legal instruments (such as the Non-Proliferation

114 Nuclear Energy Institute, "DOE Summit Raises Urgency of Preserving Existing Nuclear Plants," May 20, 2016, http://www.nei.org/News-Media/News/News-Archives/DOE-Summit-Raises-Urgency-of-Preserving-Existing-N.

115 Various EIA Data Sources, http://www.eia.gov/nuclear/generation/index.html, https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11, http://www.eia.gov/todayinenergy/detail.php?id=26232. This calculation was performed by replacing 17.7 percent (17.5 out of 99 operating units) of nuclear power generation with electricity from other sources proportional to their current share of the U.S. electricity matrix and estimating the resulting change in CO2 emissions.

116 This calculation was performed by dividing 140 TWh (17.7 percent of 797 TWh of nuclear power generation in 2015) by the approximately 310 TWh generated by solar and other non-hydro renewables. See U.S. Energy Information Administration, "Electric Power Monthly," May 25, 2016,https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_1.

Treaty) and institutions (such as the International Atomic Energy Agency and the World Institute for Nuclear Security) to multilateral efforts (such as the Nuclear Security Summits launched by President Obama) and diplomatic initiatives (such as efforts to contain the Iranian and North Korean nuclear threats). And it highlighted the potential for an Assured Nuclear Fuel Services Initiative to help restore American leadership in the global fight to reduce nuclear risks while minimizing the demand for dangerous technologies that could spread global access to highly-enriched uranium or plutonium that could fuel the spread of nuclear weapons.

This report will embrace the findings of its companion, while at the same time acknowledging safety as sharing the prime importance accorded to security when it comes to developing nuclear energy programs. This is not only true as a matter of ethics, law, and regulation, but also as a matter of practicality: time and again we have seen how safety problems can deeply corrode public support for nuclear power and lead to significant costs. The Nuclear Regulatory Commission was split off from the Atomic Energy Commission in 1974 precisely in order to assure that the governmental oversight for nuclear safety was not diluted or put into a possible conflict of interest by serving in the same organization that had responsibilities for the promotion of nuclear power.

That fundamental importance of safety has played out as nuclear accidents over the years set back the prospects for nuclear power. Each accident triggered efforts to learn and apply the appropriate lessons. For example, review of the 1979 Three Mile Island accident led to the establishment of the Institute of Nuclear Plant Operations (INPO), which is dedicated to promoting the highest levels of nuclear safety and reliability through reactor evaluations, training and accreditation, incident analysis, and coordination of emergency response. The years following Three Mile Island also witnessed the development of a new generation of reactor designs that relied less on pumps and human action and more on passive safety; cooling water might be stored, for example, above the reactor core, so that the fail-safe force of gravity would draw the water down to cool the core before a meltdown could occur. That safety measure would not depend on pumps functioning or the availability of power from the grid.

Review of the 1986 Chernobyl accident focused on the "positive void coefficient" of the RBMK reactor design, in which the loss of coolant entailed in a reactor incident actually led the reactor to overheat even more, in a vicious

cycle that could lead to core meltdown and major radiation releases. International cooperative efforts to respond to the Chernobyl accident led to the establishment of the World Association of Nuclear Operators (WANO), an international group of nuclear power plant operators dedicated to safety and to carrying out their mission through peer reviews of nuclear plants around the world. The organization also runs other programs to provide technical support and information exchange to help promote nuclear safety. Like INPO, WANO seeks to embed the culture of nuclear safety throughout the nuclear industry worldwide.

Over time, these efforts began to increase public confidence in nuclear safety and, combined with rising concerns over global warming and the need to cut CO_2 emissions, persuaded many in the environmental community that the contributions nuclear energy could make to reducing carbon emissions outweighed the safety and environmental risks of nuclear power. As large-scale generators of carbon-free, baseload power, nuclear plants could easily substitute for the U.S. coal-fired power plants. In 2015 these plants emitted approximately 1.36 billion tons of carbon dioxide, accounting for 71 percent of total U.S. power plant emissions.[117]

In 2006, Patrick Moore, an early Greenpeace activist, abandoned his opposition to nuclear power, explaining that his former belief that "nuclear energy was synonymous with nuclear holocaust," had changed over thirty years "because nuclear energy may just be the energy source that can save our planet from another possible disaster: catastrophic climate change."[118] The significance of this comment lies less in the analytical underpinnings of his views, before and after they changed, than in the fact that growing concerns over carbon and the climate threat could persuade even a profound skeptic of the value of nuclear energy.

The growing support for nuclear power gave hope to the nuclear industry, which started to prepare what some called a "Nuclear Renaissance" that would

117 EIA figures for 2015 show CO_2 emissions of 5,271 metric tons, allocated by power sector: 71 percent coal, 28 percent natural gas, 1 percent petroleum, and 1 percent other, http://www.eia.gov/tools/faqs/faq.cfm?id=77&t=11;

118 Patrick Moore, "Going Nuclear," *Washington Post*, April 14, 2006, http://www.washingtonpost.com/wp-dyn/content/article/2006/04/14/AR2006041401209.html. The Fukushima accident did not shake Moore's conviction regarding the need for nuclear energy; see http://forumonenergy.com/2013/07/22/the-pro-nuclear-environmentalist-movement-a-qa-with-dr-patrick-moore/. Other noted environmentalists who support nuclear energy as part of the solution to the climate challenge include James Hansen (former director of NASA Goddard Institute for Space Studies), James Lovelock (chemist and inventor), and Stewart Brand (editor of *The Whole Earth Catalogue*).

usher in a new era of expanding nuclear power. Others considered that expression ill-advised and over-confident, in the unfortunate tradition of the phrase "electricity too cheap to meter."[119] The others were right. The expression died along with the hopes it expressed on March 11, 2011, when Japan was hit by a 9.0-magnitude earthquake, followed by an approximately 45 foot tsunami. The tsunami killed 16,000, destroyed 300,000 buildings, and created a massive humanitarian crisis for Japan, dramatically compounded by the consequent nuclear accident at the Fukushima Dai-ichi nuclear plant.[120]

The Unit 4 reactor building of the crippled Fukushima Dai-ichi nuclear power station is seen through a bus window in Okuma, Japan Saturday, Nov. 12, 2011. (AP Photo/David Guttenfelder, Pool)

When the earthquake struck, three of the six reactors at the Fukushima Dai-ichi site shut down (the other three were already shut down for refueling and maintenance) and emergency diesel generators started operating to provide emergency power to reactor safety systems. Unfortunately, the tsunami

119 This phrase was coined in a 1954 speech by Lewis Strauss, chairman of the Atomic Energy Commission, about the potential for electric power generation in general, not about nuclear power in particular.

120 Motoko Rich, "Earthquake off Fukushima, Japan, Triggers Tsunami," *New York Times*, November 21, 2016, http://www.nytimes.com/2016/11/21/world/asia/japan-earthquake.html.

subsequently swamped all but one of the diesel generators and short-circuited the electrical buses, which resulted in three of the reactors overheating. The overheating of the three reactors caused the reactor fuel to melt, producing a reaction that led to hydrogen explosions, and a subsequent release of radiation to the environment. Unit 4, one of the reactors that was shut down for refueling at the time of the tsunami, was also damaged in the subsequent explosions.

Of course, the Japanese government took the lead in responding to this disaster, but the United States and others in the international community immediately rallied to help Japan in its hour of need, providing equipment, expertise, and general humanitarian support in the wake of the nuclear accident. Initially, efforts focused on restoring cooling to the Fukushima Dai-ichi reactors, to stabilize the situation. Subsequent efforts addressed the removal of massive amounts of contaminated debris, the collection and treatment of contaminated water, the design and construction of structures to reduce further contamination of water through the site, and many other daunting challenges. It is an enormous task. The cleanup and decommissioning of the four damaged reactors at Fukushima has just marked its fifth anniversary, and the whole job is expected to cost around $200 billion and take decades to complete.[121]

Fukushima gave rise to a thoroughgoing reexamination of nuclear safety measures, practices, and procedures by nuclear plant operators and safety regulators worldwide.[122] Germany, which the year before had decided to extend the lives of its fleet of seventeen nuclear reactors from 2022 to 2032, abruptly reversed course and decided to retire eight reactors at once and the rest of the fleet by 2022. Elsewhere, nuclear plant projects were abandoned or put on hold. The IAEA convened a ministerial conference in June 2011, which led to the preparation of an Action Plan on Nuclear Safety that called for strengthening of nuclear safety assessments, peer reviews, emergency preparedness and response, safety assessments, and legal and regulatory frameworks. Among other things, the plan properly emphasized the importance of clear and accurate reporting of the facts about any nuclear incident to the public.

Eventually, most governments reached the same conclusion President Obama did. He pronounced from the Rose Garden on March 17, just six days after the

121 Mayumi Negishi, "Japan Raises Estimate for 2011 Nuclear Accident to $200 Billion," *Wall Street Journal*, December 9, 2016, http://www.wsj.com/articles/japan-raises-estimate-for-2011-nuclear-accident-to-200-billion-1481270326.

122 International Atomic Energy Agency, "IAEA Action Plan on Nuclear Safety Dashboard," http://www-ns.iaea.org/actionplan/.

tragedy at Fukushima, that nuclear power would remain part of our long-term low-carbon energy portfolio:

> Here at home, nuclear power is also an important part of our own energy future, along with renewable sources like wind, solar, natural gas, and clean coal. Our nuclear power plants have undergone exhaustive study, and have been declared safe for any number of extreme contingencies."[123]

In August 2015, after four years of review, IAEA Director General Yukia Amano released the agency's exhaustive report on the causes of the Fukushima accident and the lessons learned. The report documented a litany of human, organizational, and technical shortcomings, including divided responsibilities, poor planning and unwarranted assumptions, inadequate emergency preparedness and response mechanisms, and much more. In releasing the report, Amano emphasized that "everything humanly possible must be done to ensure that no such accident ever happens again. This is all the more essential as global use of nuclear power is likely to continue to grow in the coming decades."[124]

123 Jesse Lee, "President Obama: We Will Stand with the People of Japan," *White House Blog*, March 17, 2011, https://www.whitehouse.gov/blog/2011/03/17/president-obama-we-will-stand-people-japan.

124 International Atomic Energy Agency, *The Fukushima Daiichi Accident: Report by the Director General* (2015), http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1710-ReportByTheDG-Web.pdf. For other assessments of the causes of the accident and recommendations, see *The National Diet of Japan: Fukushima Nuclear Accident Independent Investigation Commission,* The National Diet of Japan, Kiyoshi Kurokawa, chairman (2012), https://www.nirs.org/wp-content/uploads/fukushima/naiic_report.pdf, and National Academy of Sciences, *Lessons Learned from the Fukushima Nuclear Accident for Improving Safety of U.S. Nuclear Plants* (2012), https://www.nap.edu/download/18294.

Recommendation 7:
Infuse nuclear safety and security culture through best practices and peer reviews.

Nuclear power must always put safety and security first. While other energy forms inflict clear, known, and measurable damage to society—for example, mining deaths, lung cancers caused, communities flooded, etc.—the invisible nature of radiation and the fear it inspires give nuclear safety and security concerns a place of their own in the political firmament and environmental agenda. That said, some of the safety benefits of nuclear power are equally invisible. For example, air pollution as a result of power generation in the United States has been shown to cause 52,000 premature deaths each year, but a recent NASA study has concluded that from 1971–2009 nuclear power actually prevented an average of 1.8 million deaths worldwide as a result of the emissions that it avoided.[125]

The nuclear community strives to embrace the high standards of nuclear safety and security. Best safety practices are reviewed, refined, and promoted through a variety of forums, including the IAEA, WANO, and INPO. In 1994 a diplomatic conference convened by the IAEA promulgated the Convention on Nuclear Safety, which aims to achieve and maintain high nuclear safety standards through national standards and international cooperation, establish and maintain defenses against radiological hazards, and mitigate against radiological damages. The convention now has 78 parties.

Three Mile Island, Chernobyl, and Fukushima all showed that—whether fairly or unfairly, whether one reactor is inherently safer than another, or one country's safety practices far superior to another's—any accident in any country seriously undermines public confidence in other parts of the world. That is why the industry must vigorously implement the important safety improvements spawned by the review of the tragic events surrounding the Fukushima incident.

125 Pushker Kharecha and James Hansen, "Coal and Gas Are Far More Harmful Than Nuclear Power," National Aeronautic and Space Administration, April 23, 2013, http://climate.nasa.gov/news/903/,

Pushker A. Kharecha and James E. Hansen, "Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power," *Environmental Science & Technology,* 47, no. 9 (2013): 4889–4895, doi:10.1021/es3051197, http://pubs.acs.org/doi/abs/10.1021/es3051197.

Fukushima was both a call to action and a cause for reflection within the international nuclear community. Japan has taken steps to address weaknesses in plant designs, strengthen its emergency response preparedness, and improve its regulatory framework.[126] Around the world, governments and industry have taken steps to reevaluate the safety of their existing nuclear plants from environmental hazards, to create a supply of backup power sources and equipment, and to strengthen the resilience of nuclear plants to external threats. In the United States, one of the fundamental implications was the elevation of operational safety to a much higher level of focus and attention, beyond the traditional emphasis upon design safety for nuclear plants. This was reflected in the "FLEX Strategy" adopted by the U.S. nuclear industry to implement the Nuclear Regulatory Commission's Fukushima task force recommendations. FLEX relied upon portable equipment to facilitate emergency responses to events beyond the four corners of the plant's design basis.[127]

The IAEA has served as an international forum for analyzing the causes and disseminating lessons learned, resulting in the international community's strengthening the nuclear safety and security framework through the IAEA Action Plan on Nuclear Safety and the Vienna Declaration on Nuclear Safety in response to Fukushima.

The importance of a robust safety and security culture cannot be exaggerated. No amount of regulatory reform and no beautifully-crafted set of rules or policies can prevent a safety or security incident in the absence of such a culture. A strong safety and security culture starts by acknowledging that perfection is unattainable. The question is how best to build a culture that is most likely to avoid complacency and to minimize risk—fostering an environment that learns from every accident or near miss—through a spirit of continuous vigilance and improvement.

Such vigilance, however, does not mean that each accident should produce a new rule. Often bureaucracies respond by layering on a new rule on top of the existing regime, without really understanding the root cause of the incident. The result can be a clutter of rules and red-tape that rob the system of clarity without enhancing safety or security. It is better to start by taking the time and effort to examine the safety culture and find out what happened in the incident and why; it may be that the rules were poorly designed or inadequate, or that the culture did not support

126 *The Fukushima Daiichi Accident: Report by the Director General* (2014); http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1710-ReportByTheDG-Web.pdf

127 FAQ: Nuclear Energy Industry Develops FLEX Strategy to Increase Safety, Address, NRC's Post-Fukushima Recommendations," safetyfirst.nei.org.

their effective implementation, or that unpredictable human error caused the problem even if the rules and culture were all appropriate.

Generally, a questioning environment that expects individuals to use their eyes, ears, and brains to be vigilant, situationally aware, and comfortable reporting concerns without fear of retribution is likely to be safer than one where an ever-thickening manual of expanding regulations leads first-line workers and even supervisors to a "compliance by clipboard" mentality in which they focus on mechanistic interpretation of complex rules and procedures at the risk of missing something important that could be detected through the use of all their faculties, observational and analytical.

That is why it is so important to continue supporting organizations like INPO, WANO, and the World Institute for Nuclear Security (WINS). In their own, undramatic way, these organizations can foster and sustain a deep and abiding focus on safety and security that will always be of critical importance to the ability of nuclear energy to remain a viable energy source in the years to come. And when it comes to security, it is vital to focus not only on the risk of terrorists or state actors gaining access to nuclear weapons, but also on the physical protection of reactors and fuel facilities, as well as hospitals, universities, and any other facilities where nuclear materials could be vulnerable to attack—whether by criminals, terrorists, or state-backed commandos.

8. **And, in the end ...**

Another major concern surrounding nuclear power relates to managing its byproducts, including isotopes within the used fuel elements withdrawn from the reactor, which remain radioactive for hundreds of thousands of years. This is a challenge that is faced by all nations utilizing nuclear power; few have dealt with the issue effectively. The most successful program is under way in Finland, which has made considerable progress towards establishing an operational nuclear waste repository site. From the start Finland relied on a "consent-based approach" that took into account the "societal values" of the community in which the repository would be located. Finland identified potential sites using a clear multistep process that yielded four locations, some of which had strong local support for hosting a repository. Indeed, as part of its application to construct the repository that it submitted to the Finnish

government, the construction company had to have statements from the local municipality demonstrating community support.

The site of Onkalo, about five kilometers from the neighboring Olkiluoto nuclear power plant, was selected in 2000. The local municipality issued a building permit in 2003 and excavation work at the site began the following year. In November 2015 the Finnish government reached another milestone, authorizing construction at the site of a €1 billion facility, comprised of a network of tunnels dug through granite 450 meters below the earth's surface. Copper canisters will be packed in clay in the tunnels, storing 6,500 metric tons of used nuclear fuel. The facility is expected to start accepting used fuel shipments around 2023 and will continue doing so for the rest of the century, at which point the tunnels will be backfilled and sealed. The lifetime operating cost of the facility is projected to be $3.8 billion.[128]

On the day his company, Posiva, received the Finnish government's construction license for Onkalo, CEO Janne Mokka said, "This is a huge step for us. We've done research and development work for this for more than forty years."

Alas, the United States has been working the issue even longer, but with less success. Despite legislative efforts dating to the 1982 passage of the Nuclear Waste Policy Act, which provided a comprehensive approach to the problem, the issue at this writing remains unresolved and mired in bitter controversy. In 1987 the Congress amended the 1982 Act, designating Yucca Mountain, Nevada, as the only site to be characterized for long-term storage of nuclear waste from across the country.[129] This fateful step, essentially the opposite to the consent-based approach taken in Finland, had predictable results: Nevadans objected. For years their opposition was spearheaded by Nevada Democrat and longtime Senate leader, Harry Reid. The Obama administration tried to cancel the project by defunding it, but supporters continue to fight to place that material at Yucca. With President Obama and Senator Reid now retired from the political scene, it remains to be seen whether Yucca Mountain supporters will succeed in reviving the project.

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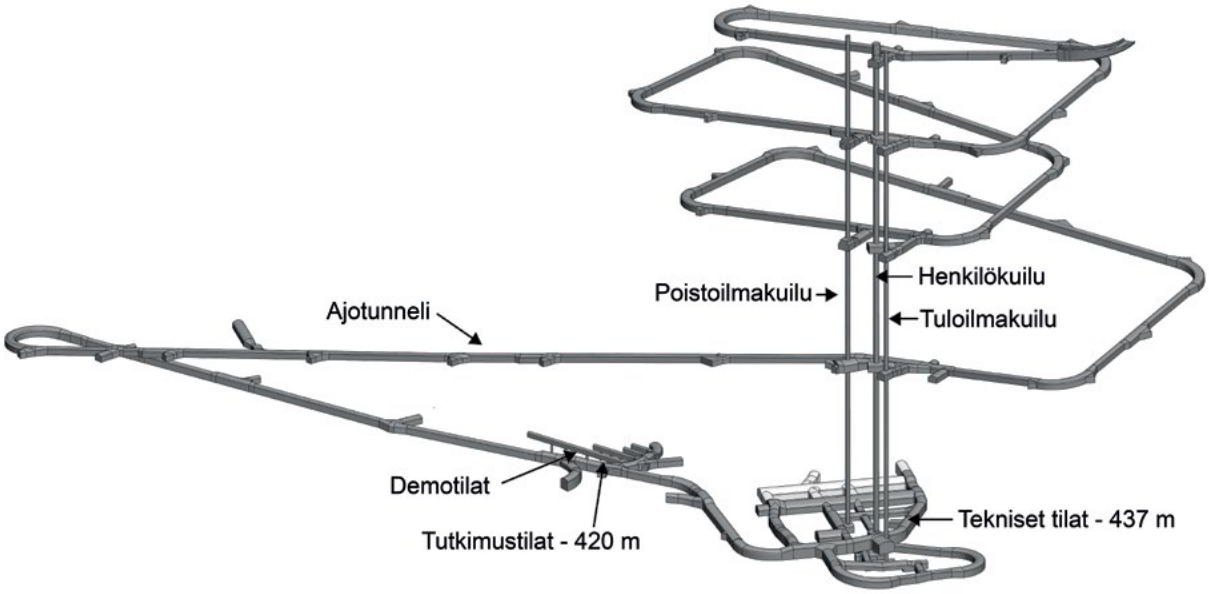
128 Jussi Rosendahl, "Finland Approves Underground Nuclear Waste Storage Plan," *Reuters*, November 12, 2015, http://www.reuters.com/article/us-finland-nuclear-idUSKCN0T121120151112.

129 Matthew L. Wald, "Bury the Nation's Nuclear Waste in Nevada, Bush Says," *New York Times*, February 16, 2002, http://www.nytimes.com/2002/02/16/us/bury-the-nation-s-nuclear-waste-in-nevada-bush-says.html?_r=0; Nuclear Energy Institute, "Yucca Mountain Myths and Facts Opponents Distort or Ignore Research," February 2011, http://www.nei.org/Master-Document-Folder/Backgrounders/Fact-Sheets/Yucca-Mountain-Myths-and-Facts-Opponents-Distort-o.

The “Onkalo” spent nuclear fuel repository, Eurajoki, Finland



A three-dimensional diagram of the Onkalo facility. (Posiva Oy Olkiluoto)

A demonstration tunnel at Onkalo in 2009. (Posiva Oy Olkiluoto)

In walking away from the Yucca Mountain project, the Obama administration convened a Blue Ribbon Commission on America's Energy Future (BRC), co-chaired by retired Congressman Lee Hamilton and retired Lt. Gen. Brent Scowcroft, with the mandate to review policies for managing the back end of the nuclear fuel cycle and recommend a new plan.[130] The 2012 BRC report reached a series of sensible conclusions, beginning with the central and obvious point that any solution in order to be successful would need to be based on the consent of the community hosting the facility, an approach that worked so well in Finland that two communities ended up competing for the right to host the geologic repository.[131]

Another promising development has arisen in Australia. Australia is one of the world's leading suppliers of natural uranium, and has a strong record in nonproliferation as well as a modestly scaled but well respected nuclear research and development program, based at the Australia Nuclear Science & Technology Organisation (ANSTO). That said, Australia has never opted to build nuclear power stations, and the issue of playing a larger role in global nuclear commerce has been controversial domestically. So has the issue of putting a price on carbon emissions. The Labor government led by Julia Gillard did so in 2012, only to have it repealed under the Liberal government of Tony Abbott in 2014.

Meanwhile, interest in expanding Australia's nuclear industry beyond mere mineral extraction has persisted. In February 2015 Governor Jay Weatherill of South Australia (home of two of Australia's three operating uranium mines) announced the formation of a Royal Commission on the Nuclear Fuel Cycle to explore the possibility of South Australia becoming more involved in developing economic opportunities around the fuel cycle. Weatherill appointed former South Australia Governor Kevin Scarce to lead the commission, which solicited opinions widely and held a series of public sessions in the course of their work. In the background of the Royal Commission's work stood the harsh reality that unemployment in South Australia had reached a fifteen-year peak (7.7 percent), the highest in Australia, while the state ranks seventh in

130 Blue Ribbon Commission on America's Nuclear Future, *Report to the Secretary of Energy* (January 26, 2012), http://energy.gov/sites/prod/files/2013/04/f0/brc_finalreport_jan2012.pdf.

131 Blue Ribbon Commission report, 49.

economic performance out of the eight Australian states.[132] (Only Tasmania ranks lower.)

The findings of the Royal Commission, announced May 6, 2016, concluded that South Australia could indeed benefit economically from increased participation in the nuclear fuel cycle if there were sufficient community consent and bipartisan support. Interestingly, the Royal Commission did not find a near-term case to build nuclear power plants and did not view further uranium extraction as the highest value-adder. Rather, it recommended that

> The disposal of used fuel and intermediate level waste (ILW) could be undertaken safely in a permanent geological disposal facility in South Australia. This would have the potential to deliver significant intergenerational economic benefits to the community. The key recommendation in this regard is that the South Australian government pursue the opportunity to establish used nuclear fuel and ILW storage and disposal facilities South Australia …[133]

The findings recommended the establishment of a state wealth fund "to ensure benefits are shared across the community."[134] This finding made sense in light of the fact that parts of South Australia have some of the best geologies in the world for the storage of nuclear waste: dry, flat, remote, and seismically inactive. And Australia is an exemplar of strong nonproliferation credentials on the world scene.

132 Commonwealth Securities, *State of the States: January 2016 State & Territory Economic Performance Report* (January 2016), https://www.commsec.com.au/content/dam/EN/Campaigns_Native/stateofstates/January2016/CommSec_State_of_the_States_January2016.pdf; ABC News, "South Australia On Track to Become Nation's Worst Economy as Jobs, Construction, Retail Falls," October 26, 2015, http://www.abc.net.au/news/2015-10-26/sa-on-track-to-become-nation's-worst-economy/6884070.

133 Royal Commission, Government of South Australia, *Nuclear Fuel Cycle Royal Commission Report* (May 2016): 170, http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf.

134 Royal Commission Report, 106.

Recommendation 8: **Implement a consent-based approach to nuclear waste disposal in the United States.**

The BRC achieved a consensus report that advocated a sensible, practical set of recommendations, and represents the best chance since the passage of the 1982 Nuclear Waste Policy Act to resolve this vexing issue in the U.S. The recommendation of this section focuses on the central finding of the BRC, but several others should be included in the new legislation proposed here. For instance, the BRC report proposed shifting responsibility for repositories and storage facilities from the DOE to a newly created organization, taking prompt action to develop a geological repository and one or more waste storage facilities, launching a cooperative effort to plan for future fuel transport to these sites, and maintaining an active leadership role in the world on nuclear issues.

Despite the BRC's work, tangible progress towards a permanent repository has been meager. Nuclear waste in the United States continues to be stored in "temporary" locations, with four-fifths at water pools at reactor sites and the rest in dry cask storage; ultimately geological disposal for that nuclear waste will be required.[135] In the meantime, in 2016 Waste Control Specialists LLC filed an application with the Nuclear Regulatory Commission to build a consolidated interim storage facility for used fuel from a number of reactors which, if licensed and built, could bridge the current situation of used fuel piling up at every US reactor site, including those where the reactors have ceased operating, to the eventual long-term solution of geologic disposal.[136]

Senator Lisa Murkowski (R-AK) has led Senate efforts to translate the BRC findings into law, an effort that could finally provide a long-term solution to the used fuel conundrum. Although passions on this issue run high in the House of Representatives, should the Senate pass BRC implementing legislation, it may create some momentum that will carry over to the House, especially if the U.S. nuclear industry gets behind the effort. If such a bill becomes law, it could not only resolve a major nagging concern regarding the

135 U.S. Nuclear Regulatory Commission, "Spent Fuel Storage in Pools and Dry Casks: Key Points and Questions & Answers," last updated April 13, 2015, http://www.nrc.gov/waste/spent-fuel-storage/faqs.html.

136 See NRC license application NRC, Waste Control Specialists LLC, DOCKET NO. 72-1050, APPLICATION FOR A LICENSE FOR A CONSOLIDATED INTERIM SPENT FUEL STORAGE FACILITY, https://www.nrc.gov/docs/ML1613/ML16133A100.pdf

future of nuclear power in the United States, but also help establish a foundation for successful nuclear waste disposal efforts around the globe.

9. Not too cheap to meter, but ...

Regarding cost, the work is still cut out for nuclear power. Hyperbole in business and government usually backfires. For years nuclear critics excoriated nuclear boosters from the age of Reddy Kilowatt in the 1950s, scoffing at the vainglorious claim that nuclear power would generate electricity "too cheap to meter."[137]

"Reddy Kilowatt" served as "corporate spokesman" for electricity generation in the United States and other countries for over seven decades..

Ironically the "too cheap to meter" comment was misattributed; in fact, the comment referred not to nuclear power but rather to electricity generally. But perhaps because the source of the comment was a 1954 speech to the National Association of Science Writers by Atomic Energy Commission Chairman Lewis Strauss, the phrase became linked to nuclear power in the public consciousness.

137 Reddy Kilowatt was a cartoon character used by the energy industry to "humanize electric utility service." Originally created in 1926, Reddy Kilowatt was prevalent in industry advertising and outreach programs in the 1950s and 1960s; Smithsonian Institute, American History Museum, http://amhistory.si.edu/archives/AC0913.htm.

Of course nuclear power has never lived up to that billing; no energy source could. On the contrary, nuclear power has consistently failed to live up to its promoters' cost estimates. According to I. C. Bupp, an economic analyst of the early commercial nuclear industry, "In the heady years of the early 1970s, with the apparent worldwide triumph of American reactor technology, all that was really clear was that the cost of plants sold … would bear slight resemblance to the promises of their sales agreements.… On the average, the cost of all of the light water plants ordered in the mid- and late 1960s was underestimated by more than a factor of two in constant dollars."[138]

For the twenty-three states with deregulated electricity markets—where "merchant" power plants must sell their power on the open market, in competition with all other generators—the cost problem for nuclear power is more acute.[139] Former Exelon CEO John Rowe famously said that to justify building a new nuclear power plant in a deregulated electricity markets required natural gas prices of $8 per MBtu and carbon prices of $25 per ton.[140]

At this point, we have neither $8 natural gas prices nor a $25 price on carbon emissions, for many reasons. First, the shale gas revolution badly eroded the business case for new nuclear plant construction. When natural gas prices rose to $12 per MBtu in 2008, and bipartisan legislation to impose a price on carbon was moving forward in the Congress, nuclear power was looking increasingly attractive, and fourteen utilities were planning to build twenty-one plants in the United States.[141] But the huge increase in shale gas production—from 1.3 trillion cubic feet (Tcf) in 2007 to 13.4 trillion Tcf in 2014—brought natural gas prices down below $3 per MBtu, and the reference

138 Irvin C. Bupp and Jean C. Derian, *Light Water: How the Nuclear Dream Dissolved* (New York: Basic Books, 1978), 76, 79.

139 In the 1990s, following passage of energy legislation that promoted competition there, twenty-three states deregulated their electricity market in whole or in part, forcing electric power generators to compete for business on the basis of cheapest rates. The California energy crisis of 2000-2001 and other factors led a number of states to repeal or delay their deregulation efforts. Tyson Slocum, Director, Public Citizen's Energy Program, "The Failure of Electricity Deregulation: History, Status and Needed Reforms" (March 2007), 5; https://www.ftc.gov/sites/default/files/documents/public_events/Energy%20Markets%20in%20the%2021st%20Century%3A%20Competition%20Policy%20in%20Perspective/slocum_dereg.pdf

140 Katherine Ling, "Nuclear Power: What Does $36B Buy Democrats?" *E&E News*, February 9, 2010, http://www.eenews.net/stories/87390.

141 World Nuclear Association, "U.S. Nuclear Power Policy," last updated December 2016, http://world-nuclear.org/info/Country-Profiles/Countries-T-Z/USA--Nuclear-Power/,

case of the Energy Information Administration projects Henry Hub spot natural gas prices to remain below $8 per MBtu through 2040.[142,143]

Second, we still have no price on carbon emissions. If we did, it would further help level the playing field between nuclear power and fossil fuel burning plants.

Third, some regulatory measures labeled as "pro-environment" further aggravate the problem. As this report has noted, many so-called "green" policies—including mechanisms such as renewable portfolio standards, the investment tax credit, and the production tax credit —favor wind and solar over nuclear, tilting the playing field to favor some non-carbon emitting sources or electricity more than others.[144] These state policies can also influence federal policies. For instance, the Department of the Navy and the California Energy Commission agreed in October 2016 to several mutually beneficial steps to promote California's greenhouse gas goals, but because of the states' carve-out for renewables the steps were exclusively focused on renewables.[145] The agreement included steps such as developing the largest solar photovoltaic facility on Department of Defense land, showing the power of defense procurement in shaping our climate agenda. Perhaps the Department of Defense could offer long-term power purchase agreements, whose predictable cash flows could support investment in advanced reactors.

Fourth, deregulated markets may not recognize another advantage inherent in nuclear power: reliability. The polar vortex that descended into the upper Midwest January 2014 drove home this message. The brutal cold froze coal stacks, sent natural gas prices soaring, and triggered major power outages. Half of those outages came from natural gas plants and over a third from coal plants. Meanwhile, nuclear power plants kept humming along at 95 percent

142 U.S. Energy Information Administration, Natural Gas, "U.S. Shale Production," December 14, 2016, https://www.eia.gov/dnav/ng/hist/res_epg0_r5302_nus_bcfa.htm.

143 U.S. Energy Information Administration, Natural Gas, "Henry Hub Natural Gas Spot Price," February 1, 2017, https://www.eia.gov/dnav/ng/hist/rngwhhdd.htm.

144 Exelon CEO Chris Crane has suggested that subsidized wind power was also placing significant pressure on utilities to close nuclear plants stating, "What worries me is if we continue to build an excessive amount of wind and subsidize wind, the unintended consequence could be that it leads to shutting down plants." Quoted in *Chicago Tribune,* February 8, 2013; http://articles.chicagotribune.com/2013-02-08/business/ct-biz-0208-exelon-div--20130208_1_exelon-nuclear-plants-power-plants. Crane, along with other energy industry executives, has been vocal in his opposition to subsidies for wind power such as the PTC on the grounds that wind subsidies are no longer justified for a multi-billion dollar industry, distort energy prices, and ultimately diminish the economic viability of baseload power generation like nuclear power plants.

145 Department of the Navy, "Navy and Energy Commission Agree to Partner on Renewable Energy Projects," October 13, 2016, http://www.navy.mil/submit/display.asp?story_id=97131.

capacity.[146] But nuclear owners and operators are typically not compensated for the resilience of baseload nuclear power and the vital role that it plays in U.S. energy security. One way to address this problem is through "capacity markets", where grid operators hold auctions that procure power years before it is needed from generators, thus providing assurance that the power will be there when needed, *e.g.,* in a subsequent grid emergency. When nuclear power generators successfully compete in capacity markets they do receive compensation for the reliability of the power that they offer to consumers.[147] That said, capacity markets that provide a revenue stream a few years into the future do not have the power of a long-term power purchasing agreement to provide confidence in a revenue stream sufficient to underwrite the multibillion dollar capital investment required to commit to the construction of a nuclear power plant.

A Nov. 23, 2015 overhead view of the AP-1000 reactors under construction at the Vogtle Plant in Waynesboro, Georgia. (Landsat / Copernicus, used with permission)

146 James Conca, "Polar Vortex—Nuclear Saves the Day," *Forbes,* January 12, 2014, http://www.forbes.com/sites/jamesconca/2014/01/12/polar-vortex-nuclear-saves-the-day; PJM, "Analysis of Operational Events and Market Impacts During the January 2014 Cold Weather Events," May 8, 2014; North America Electricity Reliability Corporation, "Polar Vortex Review," September 2014. PJM is a regional transmission organization (RTO) in the Eastern United States. See also Exelon, "Market-Based Policy Concepts for Encouraging Fuel Diversity and Retaining Baseload Zero-Carbon Resources," December 4, 2014 http://www.ksg.harvard.edu/hepg/Papers/2014/12.14/Dominguez%20Presentation.pdf.

147 PJM Learning Center, *Capacity Markets,* https://learn.pjm.com/three-priorities/buying-and-selling-energy/capacity-markets.aspx

Nuclear power plants, once built, can run efficiently for decades, and operators have learned through long experience how to improve performance through experience. Thus even during the thirty-year hiatus when no new commercial nuclear power plants were built in the United States, improvements in the capacity factors of nuclear reactors—i.e. the percentage of time that they operated between shutdowns for maintenance and refueling—improved from 65 percent in 1978 to 91 percent in 2008.[148] That represented the equivalent of adding 30,000 MWe of additional nuclear power to the grid without adding a single new reactor, and for far less investment than a multi-billion dollar nuclear power station would require.[149]

So efficient operation can improve the lifecycle cost of a nuclear power plant. Typically, U.S. nuclear reactors receive forty-year licenses from the Nuclear Regulatory Commission (NRC), which can be renewed in twenty-year terms.[150] By 2040, half of the U.S. nuclear fleet will have been operating for sixty years and, to avoid electricity shortages from widespread retirements, utilities are now expected to begin seeking second license renewals for up to an additional twenty years of operation.[151]

While cost is an issue everywhere, the problem is less acute in regulated markets. There, the public utility commission can authorize a utility to collect rates that can finance the construction of a nuclear power plant, knowing that over time the investment can be recovered through the rates charged for the purchase of power generated by that utility. In the United States, the four new reactors that are under construction—the two Vogtle units in Georgia and the two V. C. Summer plants in South Carolina—are located in states with regulated energy markets. The first commercial nuclear power plant to begin operations in this century—the Watts Bar 2 unit in Tennessee— is owned by a government corporation, the Tennessee Valley Authority (TVA), which can also recover the investment in building the new reactor from the ratepayers that TVA serves.

148 U.S. Energy Information Administration, "Annual Energy Review, Nuclear Power Plant Operations, 1957–2011," September 27, 2012, http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0902.

149 Of course, as reactors age, they do end up experiencing operational problems as parts age and stress.

150 U.S. Nuclear Regulatory Commission, "Backgrounder on Reactor License Renewal," last updated April 29, 2016, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-reactor-license-renewal.html.

151 Nuclear Energy Institute, "Second License Renewal for Nuclear Plants," www.nei.org/Issues-Policy/Second-License-Renewal-for-Nuclear-Plants.

Recommendation 9:
Improve nuclear power economics through practice and policy.

A number of steps would be required to improve nuclear power economics in both regulated and deregulated markets. At the market level, the most powerful factor would be to place a burden on carbon emissions in one of the many ways earlier described. At the regulatory level, leveling the playing field between nuclear and other carbon-free (renewables) or carbon-reduced (natural gas) sources of power generation would also help. At the policy level, it would help if electrical grid system operators and public utility commissions would grant some consideration to nuclear power for its contributions to resilience and energy security, as when nuclear power kept Midwesterners from freezing during the 2014 polar vortex.

Looking back on that episode, Chris Crane, chief executive officer of Exelon, which owns the largest fleet of power plants in the United States, noted that nuclear plants "are highly reliable, do not need refueling for eighteen to twenty-four months at a time, and can support the needs of the grid in stress periods." Deregulated markets, however, do not price in the value of fuel source diversity. "Even in a cheap gas environment," Crane argued, "we must maintain fuel diversity in system designs to maintain grid reliability. Market design has to compensate all energy assets for their various capabilities."[152]

Some steps have already been taken to do that. In response to concerns that these avoidable nuclear plant closures will impose both economic and climate penalties, the Federal Energy Regulatory Commission (FERC) proposed that nuclear power plants be given credit for the reliable baseload power they provide to the grid. The NRC has also established an initiative (called Project AIM 2020) with the objective of streamlining regulatory processes, appropriately aligning resources with projected workload, and improving overall performance in meeting the needs of the public and the industry.[153]

Three other factors could improve the economics of nuclear power. First is simply building more reactors. Remember that U.S. utilities are now building

152 Chris Crane remarks, Resources for the Future, May 13, 2014. http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-Resources-187_Feature-Crane.pdf

153 U.S. Nuclear Regulatory Commission, "Project Aim 2020 Commission Report and Recommendations," February 18, 2015, http://pbadupws.nrc.gov/docs/ML1502/ML15023A558.html.

new commercial units for the first time in thirty years. From 1967 through 1978, reactor construction permits in the United States averaged more than twelve per year. After the 1979 Three Mile Island nuclear accident, not a single new permit was issued until 2012, while high inflation and less-than-expected growth in electricity demand led utilities to cancel plants that had already been ordered.

When an industrial base atrophies, and the skilled craft labor accustomed to the highly-exacting standards required for building facilities that handle radioactive materials retire or moves to other kinds of projects, error rates and delays climb. After a three-decade gap in building new commercial nuclear power plants, the resulting weakness in our industrial and supply chain presented enormous challenges to project managers at the five new plants under construction. Not surprisingly, therefore, a series of problems delayed the Vogtle and Scana projects by years and led to billions of dollars in cost overruns.[154]

Often the delays are driven not by problems at the reactor site, but rather "upstream" in the supply chain for critical components, which must also be manufactured to the exacting standards necessary for nuclear class safety requirements. The limited supplier base, also badly atrophied over decades of inactivity, has caused continuing headaches for nuclear project managers and has tripped up project schedules. In the case of AP1000 plants being built at the Vogtle and Summer sites in Georgia and South Carolina, respectively, the delays and cost overruns could have been even worse absent the learning curve Westinghouse developed in building the Haiyang and Sanmen projects in China. There, delays in delivering reactor coolant pumps that met the exacting specifications of a nuclear power plant caused serious overruns in the four AP1000 units under construction.

154 Rebecca Smith, "Nuclear Power Firms Feel Squeeze; Cost Overruns, Delays Plague Current Projects, Clouding Development of Future Reactors," *Wall Street Journal*, March 5, 2015; Columbia Regional Business Report, "New Team Takes Over $13B Reactor Project at V. C. Summer," January 4, 2016; World Nuclear News, "Watts Bar 2 Final Completion Cost Approved," February 4, 2016, http://www.world-nuclear-news.org/NN-Watts-Bar-2-final-completion-cost-approved-0402167.html.

A Jan. 1, 2015 overhead view of the Barakah Plant under construction in Barakah, UAE. (Digitalglobe, used with permission)

By contrast, when thousands of skilled workers move from plant to plant, project schedules tighten and errors decline. In the United Arab Emirates, for example, project managers and craft labor were drawn from ranks of veterans in the United States, Korea, and China. That skilled workforce—managers and craft labor alike—helped make the Barakah nuclear project the best in the world in terms of on-schedule, on-budget project management. Units 1 and 2 of the Barakah nuclear project, which when completed will have four 1400 MWe reactors purchased from South Korea, are due to inaugurate operations just three months behind schedule.[155] In contrast, the 1600 MWe Olkiluoto 3 project in Finland, where Areva is building the first European Pressurized Reactor, is €8.5 billion over budget and nine years behind deadline.[156] The second such project, at Flamanville in Normandy, France, is €7 billion over cost and six years behind schedule. Areva's disastrous project management encouraged S&P cut its debt rating to B+ in December 2014, drove the company to post a €2 billion deficit for 2015, and has left it reliant on support from

155 World Nuclear Association, Country Profiles, "Nuclear Power in the United Arab Emirates," last updated October 2016, http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/United-Arab-Emirates/.

156 World Nuclear Association, Country Profiles, "Nuclear Power in Finland," January 31, 2017, http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/finland.aspx.

the French government, which owns 87 percent of shares to settle the roughly €7 billion of net debt it currently holds.[157]

Second, greater reactor standardization would help. The lack of standardization across the nuclear industry is one drives costs higher and frustrates efforts to realize savings from economies of scale. For a variety of reasons, nuclear plants have generally been built with unique characteristics and designs to meet their individual situation. This means that nuclear plants tend to be bespoke and require special attention. This further complicates the regulatory process, construction, and supply chain by requiring individual attention rather than encouraging scalable solutions. There is an ongoing effort within the industry to encourage standardization in plant designs, regulatory processes, and other technical codes and standards of work. The NRC specifically "encourages standardized nuclear power plant designs to help enhance safety and improve the licensing process."[158] There are also initiatives within professional groups, such as the World Nuclear Association's Cooperation in Reactor Design Evaluation and Licensing (CORDEL) Working Group, to promote this standardization movement. To fully realize the benefits of the learning curve presented by new construction, more progress must be made to standardize practices nationally and globally.

Third, capital costs of nuclear power must be reduced. Doing that will require the convergence of other factors. Since so much of the cost of a nuclear power plant is driven by capital costs, which are keenly sensitive to how long it takes to build a reactor, shrinking the timeline is essential. That puts a premium on any actions that tend to increase the efficiency of project management, increase the standardization of reactor designs, and reduce the delays often associated with oversight and licensing of nuclear power reactors.

On balance, the combination of existing factors make new building for nuclear inconceivable in merchant markets in the United States. Right now, when looking at their options to add power generation assets, utilities may be able to add 1,500 MWe of power in one-and-a-half years for $1.5 billion with natural gas, or the same amount of power in ten to fifteen years for $15 billion with nuclear energy. And that $15 billion project would tie up between a third and a half of a major utility's balance sheet, much more for a smaller operator.

157 Dan McCrum, "Areva's €7 Billion Shortfall and the Limits of State Aid," *Financial Times*, May 5, 2016.

158 U.S. Nuclear Regulatory Commission, "Backgrounder on New Nuclear Plant Designs," August 19, 2016, https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/new-nuc-plant-des-bg.html#certified.

Determined action can help make nuclear energy more competitive. That, in turn, would require policy makers, businesses, and citizens to embrace nuclear energy as an important element in building a low-carbon future. Putting a price on carbon emissions would have a powerful effect. Continued reform of NRC processes and procedures could result in smarter oversight that is more efficient while remaining effective. Removing statutory or regulatory discrimination against nuclear vis-à-vis other no- or low-carbon energy options will also help. So will rewarding nuclear energy for its reliable, all-weather provision of baseload capacity.

If all these issues are addressed, then even if natural gas prices remain low, nuclear power could play an important role in the building of a diversified portfolio of low-carbon energy solutions.

10. **Restoring American nuclear leadership**

For nuclear to get its groove back in the United States, however, we need to improve not only execution on current generation technology, but also look to the next generation. This is true not only because there is always room to improve in next generation technology, in every dimension—safety, security, cost, efficiency, proliferation-resistance, waste management —but also because as a nation we need to keep innovating, investing, and advancing the technology. Among other things, it will be necessary to attract more young people into the ranks of nuclear scientists and engineers to help the United States stay at the leading edge of nuclear technology globally.[159] This group will not be drawn simply by job offers. Some of them (including many of the most talented) will want to know that they are going into a field that is valued by their fellow citizens and that will make life better for their children. In short, they will want to know that nuclear power has an exciting future, important to the nation, and one in which they can make a meaningful contribution.

And that will require exciting new projects. In this vein, it is worth discussing an area that has generated substantial interest in the U.S. nuclear community: the development of small modular and advanced nuclear reactors. Nearest on

159 And if nuclear is going to fulfill its potential in helping the world close in on the 1.5°C target, we also will need to build out the ranks of qualified technicians and craft labor to staff the nuclear enterprise.

the horizon are small modular reactors (SMRs). Typically, like large conventional reactors, these units are cooled and moderated by light water, though they can be based on advanced generation technology. Their designs present a possible solution to some of the primary challenges associated with nuclear power, including high capital costs, scalability of power supply, safety, and security. SMRs produce a lower power output (300 MWe or less) than conventional nuclear power reactors (1000 MWe or more). Modular reactors can be installed in clusters, tailored to the amount of power needed at a given time. As local demand increases, additional SMRs can be added. The flexible nature of modular deployment also allows for load-following, contributing to grid stability as more renewable power generation is integrated into the grid.[160]

Another advantage is that their smaller size permits each module to be produced in a factory and then transported via truck or rail to the power plant site, thus increasing efficiency through standardization and reducing construction costs and delays. Designs small enough to be built underground afford greater physical protection against physical attack or atmospheric radiation release. Financially, advocates hope that SMRs could make nuclear power more competitive, by driving capital costs down well below the estimated $7,000 per installed kilowatt of the current conventional nuclear power plant.[161] Moreover, SMRs are designed to be passively safe, meaning that they are self-contained and not reliant on outside power sources to shut down and cool the reactor in the event of an emergency.

In December 2015 U.S. Energy Secretary Ernest Moniz spoke to the potential of SMRs on the margins of the UN climate talks in Paris:

> The proof will be in the pudding in terms of the economic performance, but it looks very promising and that can be a game-changer.… If we have a viable pathway at building nuclear power in smaller bites, the whole financing structure can change and make it much more affordable.[162]

160 Ingersoll *et al.* "Can Nuclear Power and Renewables Be Friends" (2015), http://www.nuscalepower.com/images/our_technology/nuscale-integration-with-renewables_icapp15.pdf

161 *U.S. Energy Information* Administration, Capital Cost for Electricity Plants, "Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants," April 12, 2013, http://www.eia.gov/forecasts/capitalcost/. Capital costs for nuclear power have been extensively discovered, and the data varies widely among projects, geographies, and time frames. See Jessica R. Lovering, Arthur Yip, and Ted Nordhaus, "Historical Construction Costs of Global Nuclear Power Reactors," *Energy Policy* 91(April 2016): 371–382, doi:10.1016/j.enpol.2016.01.011, http://www.sciencedirect.com/science/article/pii/S0301421516300106?np=y.

162 Alex Morales, "Nuscale Modular Reactors Can Be Game-Changer, Moniz Says," *Bloomberg*, December 7, 2015, http://www.bloomberg.com/news/articles/2015-12-07/nuscale-modular-nuclear-technology-can-be-game-changer-moniz.

Despite the advantages of SMRs, their future remains unclear. For starters, once they reach the commercial marketplace, SMRs will need to compete against natural gas and other subsidized energy sources without, at least at present, the benefit of a price on carbon emissions to help level the playing field. Moreover, while the DOE committed over $450 million to two competitively-awarded designs under the Small Modular Reactor Licensing Technical Support Program, nothing turns out to be easy when it comes to new build in the nuclear industry. Indeed, less than a year after receiving its initial award of funding, one awardee announced a drastic reduction in its budget and staffing for the project—a disappointing signal for the nascent SMR industry.[163] The other awardee, NuScale, keeps chugging along, in January 2017 submitting the first-ever SMR design certification application to the Nuclear Regulatory Commission. For its part, beyond its current program, the Department of Energy has not committed to a follow-on program to deploy SMRs after the conclusion of its current licensing program.

Part of the problem that SMRs seek to address lies in the matter of scale. Since the 1950s the average size of nuclear power reactors increased from under 100MWe to well over 1000MWe in a quest to increase the benefits of scale. The predicate of this theory was that many of the fixed costs that were major cost drivers of nuclear power—such as safety, security, and seismic requirements—were insensitive to the size of the core. Thus a larger core producing more power, spread over the same base of fixed costs, could reduce the marginal cost of each additional watt of nuclear power. One problem was that increasing scale also produced increasing complexity, which introduced greater risk of both human and technical error.

The theory of the business case for SMRs stands the traditional business model for light-water reactors on its head. It abandons the economy-of-scale approach to maximizing the *size of each plant* in favor of an economy-of-scale approach to the *production of many plants*. Modularity of design brings with it not only reduced scale but also repeatability of production, savings available from producing increased numbers, and efficiencies in terms of not needing to present the NRC with the same design over and over again. In that set of circumstances, one could expect a steeper NRC learning curve leading to faster approvals. All these efficiencies should produce increased savings as more and more SMRs are approved and deployed.

163 Navigant Research, "mPower Pullback Stalls Small Nuclear," *Forbes*, April 28, 2014, http://www.forbes.com/sites/pikeresearch/2014/04/28/mpower-pullback-stalls-small-nuclear/.

In 2012 a subcommittee of the Secretary of Energy Advisory Board gave a balanced assessment that concluded that creation of a U.S. industry building and deploying SMRs "holds considerable promise of establishing the U.S. as a global leader of civil nuclear technology, directly supporting many of the nation's high priority clean energy, national security, and economic competitive goals." But the subcommittee cautioned that establishing such an industry "is a long-term endeavor and would likely require continued sustained U.S. government support going beyond the current Small Modular Reactor Licensing Technical Support Program through the first-of-a-kind cost-recovery phase," while noting that many unknowns would bear on the outcome of these efforts.[164]

In addition to light water SMRs, which will be deployable in the mid- to late 2020s, there are many promising advanced reactor concepts being developed around the world. These fourth generation (or "Gen IV") reactors that use more advanced technologies and designs that make more efficient use of uranium resources and minimize nuclear wastes. [165] These advanced concepts hold much promise—from enhanced safety to dramatically improved economics to better proliferation resistance—to name just a few. Some designs can be operated at atmospheric pressure, which reduces the explosion and leak risks inherent in operating in a pressurized system. Many of these advanced concepts are modern extensions of previous reactor concepts that were abandoned, had earlier been abandoned. One survey found that nearly fifty companies, supported by over $1.3 billion in private capital, are developing plans for advanced reactors in the United States and Canada.[166] And the list continues to evolve.

The types of advanced concepts under development include gas-cooled reactors, ranging from high-temperature gas cooled to very-high-temperature gas cooled and the fast gas reactor; liquid metal-cooled reactors, including several different types of liquid metal coolants and moderators; molten salt reactors

164 The Secretary of Energy Advisory Board is the Secretary's senior outside advisory body under the Federal Advisory Committees Act. *See* Secretary of Energy Advisory Board, "SEAB Subcommittee on Small Modular Reactors (SMR), Draft 4–10/15," November 2, 2012, http://energy.gov/sites/prod/files/Final%20SMR%20Report.pdf.

165 Generation I reactors were early prototypes, Gen II were commercial models that began operating in the 1960s and comprise the bulk of today's global fleet, Gen III were advanced light-water reactors, and Gen IV reactors will offer highly-economical, proliferation-resistant designs with enhanced safety and minimal waste. Stephen P. Goldberg and Robert Rosner, Nuclear Reactors: Generation to Generation (National Academy of Sciences, 2011), 4; https://www.amacad.org/pdfs/nuclearReactors.pdf

166 Samuel Brinton, "The Advanced Nuclear Industry," *Third Way*, June 15, 2015. http://www.thirdway.org/report/the-advanced-nuclear-industry.

that use various fluoride and chloride salts; and even supercritical water reactors. Many of these would be fueled with uranium and plutonium, while some would introduce thorium fuel. But to give the term advanced reactor concepts its full due, we need to include various fusion devices, hybrid systems, and even nuclear battery concepts, i.e. fission devices that have no or very few moving parts, which are capable of producing a few tens of megawatts of power.

To be sure, advanced generation reactors are many years away from full-scale demonstration. A task force of the Secretary of Energy Advisory Board, charged by Secretary Moniz "to describe a new nuclear power initiative that would lead to a situation in the period 2030 to 2050 where one or several nuclear technologies were being deployed at a significant rate," recommended a multi-phase approach leading to the construction of a first-of-a-kind advanced generation reactor at commercial scale—a commitment that the task force concluded would require $11.5 billion over 25 years to fulfill.[167] That said, advanced generation nuclear reactors may turn out to be a game-changer, and the effort to develop them contributes to the intellectual vigor and rigor of an industry that has spent too long in morose introspection and needs a good jolt of excitement to drive innovation to new levels. National laboratories, universities, manufacturers, engineering firms, scientists, and some of the world's most successful entrepreneurs are engaged in this great race.

One further suggestion: in addition to building advanced generation reactors, perhaps the U.S. government could consider developing and building a new test reactor. Test reactors are smaller units that can be used to irradiate individual components or fuel ampoules to generate data on how those components or ampoules perform in the presence of fast or thermal neutrons—for example, to show whether they swell or crack. Such a reactor could assist reactor designers in their efforts to develop and test new concepts and materials here in the United States, whereas in some cases now only foreign facilities can provide the testing environment that U.S. designers require. A leading nuclear nation should have a robust domestic test bed.[168]

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167 *Secretary of Energy Advisory Board Report of the Task Force on the Future of Nuclear Power*, John M. Deutch, ch. (September 22, 2016), https://www.energy.gov/sites/prod/files/2016/10/f33/9-22-16_SEAB%20Nuclear%20Power%20TF%20Report%20and%20transmittal.pdf

168 *See* Nuclear Energy Advisory Committee, "Assessment of Missions and Requirements for a New U.S. Test Reactor" (February 2017), https://www.energy.gov/sites/prod/files/2017/02/f34/NEAC%20Test%20Reactor%20Charge%20Report%202-18-17.pdf

Recommendation 10:
Lead global development and deployment of small modular and advanced reactors.

Over the long-term, some of the most exciting possibilities for global nuclear leadership can be found in the many promising advanced reactor concepts being developed globally, using a combination of coolants and moderators including liquid metals, high temperature gases, molten salts, as well as various hybrid combinations. These reactors need substantial development but many believe they offer substantial economic and safety advantages over traditional light water cooled and moderated reactors. With respect to light water reactors, there are various small, modular concepts that are also worthy of consideration given their proven technologies and interesting financial possibilities.

To give the SMR business model a fair test, it is necessary to order a fair number. You cannot test the SMR business model if you build one or two SMRs per decade because the model itself is based on the benefits of serial production. That is why the current SMR program of the DOE is useful but not sufficient, because it does not facilitate the procurement of a substantial number of SMRs to attempt to achieve these production efficiencies.

SMRs will need committed customers in order to make the investments to build out their supply chain and to achieve the desired economies of scale successful. Congressional resolutions and academic articles favoring SMRs will not do the trick without a committed customer base to support the investments required to build a number of units. A decade ago a number of smaller nations, especially those short of available cooling water, were showing increased interest in SMRs. But Fukushima stifled those early stirrings.

Now if one wished to design a serious test of the SMR business model, one might consider facilitating the acquisition of a number of SMRs, say, two to four each that would service U.S. military bases and DOE national laboratories, respectively. Among the DOE labs, Pacific Northwest National Laboratory, Idaho National Laboratory, Oak Ridge National Laboratory, and Savannah River National Laboratory would be logical candidates, given their resident expertise in civilian nuclear energy applications and site energy requirements.

The Federal Government would not need to pick up the whole tab for building these units, for they could recoup their costs over time by selling electricity to both public and private sector ratepayers. But the benefit that these reactors could provide to the commonweal, by enhancing U.S. energy security and resilience at military bases and strategic DOE sites, could justify a public-private partnership, with cost-sharing the up-front capital between the Department of Defense and private parties involved (technology vendors, utilities, and engineering and construction contractors). They would also justify drawing from the $10 billion of the remaining loan guarantee authority available for nuclear power projects to lower the cost of capital for these SMR projects and help prove their business case sufficiently to enable the next round of SMRs to obtain the debt and equity they need entirely from commercial markets. As noted earlier, this approach successfully jump-started the grid-scale solar photovoltaic power plant market in the United States, where the DOE Loan Guarantee Program provided support for the first five grid-scale solar plants in the United States. Public capital markets provided the debt and equity to finance the next ten.

The road to building a successful nuclear future in the United States will not be easy. But the steps that need to be taken are reasonably clear. Still, there is one more argument—beyond climate, reliability, and economics—that should drive U.S. policy: nuclear power is already here to stay. The United States still has nearly 100 commercial reactors, out of 440 that exist worldwide. And sixty-six more are under construction today. So if we believe that the United States has both a lot to give in terms of promoting nuclear safety and nonproliferation, or a lot to lose by abandoning the field, then the United States should stay committed and engaged in nuclear energy. If we believe that a safety accident or a security incident anywhere is a safety accident or security incident everywhere, then the United States should stay committed and engaged on nuclear safety and security.

Some believe that the United States could continue to exercise significant and constructive leadership on nuclear safety, security, and nonproliferation even without remaining a major nuclear industrial player—either by virtue of our nuclear arsenal, our economic leverage, or moral and intellectual leadership. Others believe that the United States can remain a global technology leader even as more and more advanced manufacturing moves offshore. I am deeply skeptical; the United States must embrace advanced manufacturing, and the technology that drives it, if our Nation is to continue to prosper and lead

internationally. As the National Science and Technology Council concluded in a 2016 study:

> Advanced manufacturing strengthens the U.S. economy and national security, produces high income jobs, and generates technological innovation—driving long-term economic prosperity and growth.[169]

If the United States is to continue to play an important role in the global nuclear community, we must do all that we can, working with others, to minimize the threat of nuclear proliferation and nuclear terrorism. It will be essential to minimize the risk of diversion of nuclear technologies or materials to violent uses, whether by a rogue state or by a jihadist terrorist.

Restoring American nuclear leadership can support that vital task.

169 See, for example, the Subcommittee for Advanced Manufacuring of the National Science and Technology Council, *Advanced Manufacturing: A Snapshot of Priority Technology Areas Across the Federal Government* (April 2016), https://www.whitehouse.gov/sites/whitehouse.gov/files/images/Blog/NSTC%20SAM%20technology%20areas%20snapshot.pdf

Conclusion: **No time to delay**

Sometimes it is easier to solve a problem by breaking it apart into smaller problems. At other times it may be easier to solve a big problem if it is merged with others to create a still bigger problem, but one that breaks down artificial barriers—both economic and philosophical—and allow a comprehensive, coherent approach. The ten recommendations in this report aim to present such an approach:

Recommendation 1: **Put a price on carbon emissions.**

Recommendation 2: **Promote market mechanisms that reward efficiency.**

Recommendation 3: **Level the playing field for all lower-carbon energy sources.**

Recommendation 4: **Invest in basic research and long-term development.**

Recommendation 5: **Strengthen international cooperation.**

Recommendation 6: **Accelerate the deployment of nuclear energy.**

Recommendation 7: **Infuse nuclear safety and security culture through best practices and peer reviews.**

Recommendation 8: **Implement a consent-based approach to nuclear waste disposal.**

Recommendation 9: **Improve nuclear power economics through practice and policy.**

Recommendation 10: **Lead global development of advanced reactors.**

If implemented, these actions will provide clean energy to drive American economic growth, technological breakthroughs, and innovation; stimulate advanced American manufacturing and the jobs that go with it; and bring greater prosperity and a cleaner environment to all. And this can be achieved while also addressing both climate change and nuclear dangers.

No one has a monopoly on wisdom or the right answers when it comes to these issues, and others can improve on these recommendations or propose better ones. But we will not solve these problems unless we engage in a serious discussion involving all stakeholders in government, industry, and civil society. We must find ways to encourage actions across a wide array of

stakeholders, from political leaders and ordinary citizens, scientists and engineers, teachers and students, law enforcement and intelligence, investors and philanthropists, workers and nongovernmental organizations, religious and lay counselors, and many more. The most effective steps will be those that can engender widespread support, while aligning virtuous outcomes with actions that can be driven by self-interest.

Now, at the beginning of a new presidential administration, is the right time to have that discussion, aimed at providing concrete solutions to people in desperate need of them.

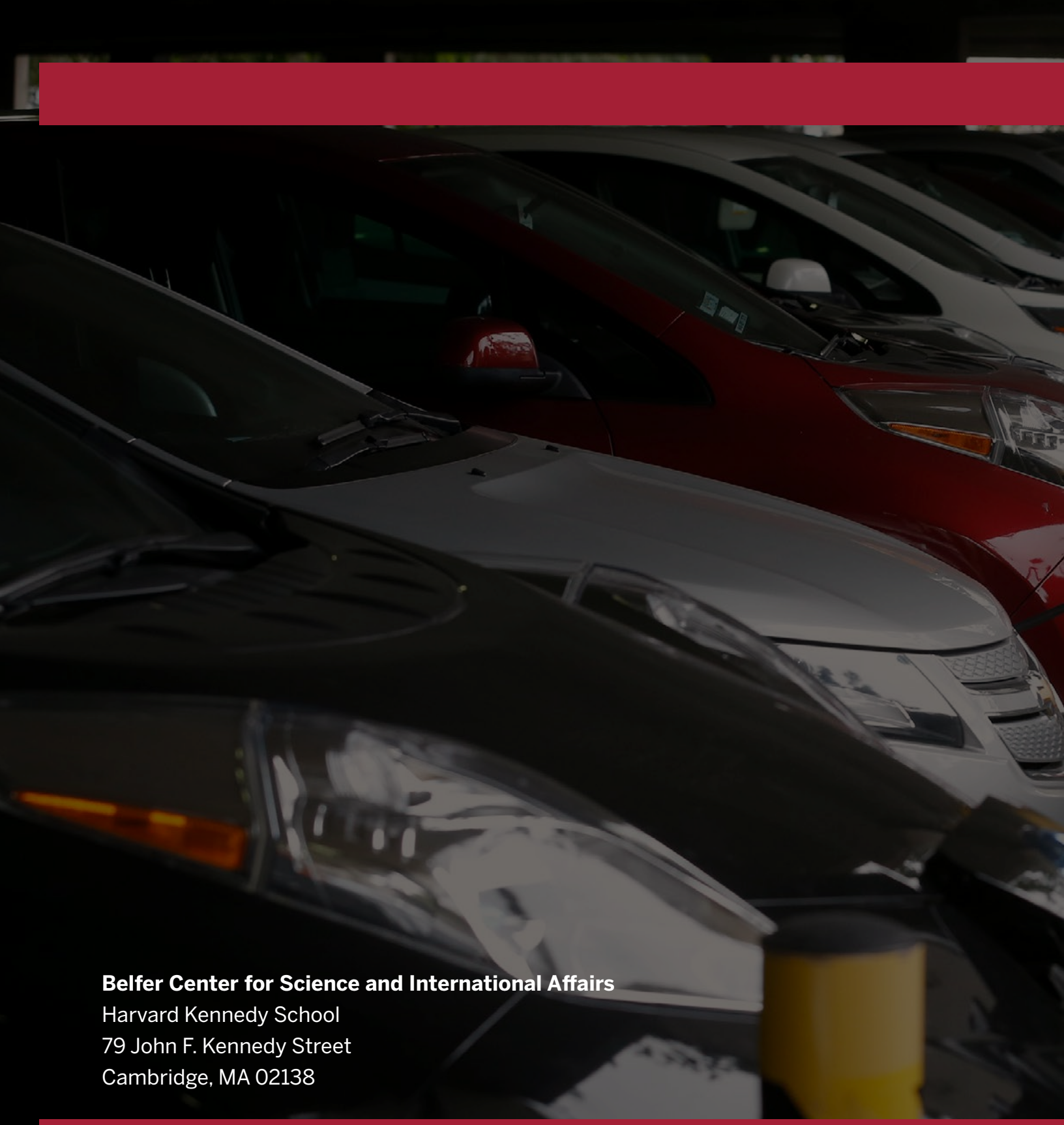
Success will require a sustained and consistent effort, no matter what policies are embraced. Adopting one initiative only to reject it a few years later, investing in one approach only to abandon it, or passing a law only to repeal it, will guarantee failure. Sadly, the polarization of American politics has led to majorities jamming unwanted decisions on minorities and minorities resorting to any available tactics to trip up majorities. Somehow we need to find a way to overcome our partisan rancor and establish a bipartisan consensus that can support a safe, secure, and prosperous future for all Americans.

The challenges are clear. We know what we need to do to save humanity and our planet. We must take vigorous action to reduce greenhouse gas emissions across industries, across nations, across oceans, and across generations. We must also take vigorous action to reduce nuclear threats across the same dimensions. A coherent American energy policy can make an indispensable contribution to our efforts to combat both the threat of nuclear annihilation and the threat of catastrophic climate change, while promoting the prosperity and happiness of all Americans. Given the stakes, there is no time for delay.

Glossary

ANSTO	Australian Nuclear Science and Technology Organization
C	centigrade
CO2	carbon dioxide
CCS	carbon capture and sequestration
COP.	UNFCC Conference of Parties
DOE	Department of Energy
GHG	greenhouse gases
GT	gigatons
GW(e)	gigawatt (electric)
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
INPO	Institute of Nuclear Power Operations
MIT	Massachusetts Institute of Technology
MW(e)	megawatts (electric)
INDC	independent nationally-determined contributions
IPCC	Intergovernmental Panel on Climate Change
NATO	North Atlantic Treaty Organization
NSG	Nuclear Suppliers Group
OECD	Organization of Economic Cooperation and Development
WNA	World Nuclear Association
WINS	World Institute for Nuclear Security
WANO	World Association of Nuclear Operators
NRC	Nuclear Regulatory Commission
RBMK	a Soviet-designed graphite-moderated nuclear reactor

BRC	Blue Ribbon Commission on America's Nuclear Future
MBtu	million British thermal units
Tcf	trillion cubic feet
ITC	investment tax credit
PTC	production tax credit
TVA	Tennessee Valley Authority
FERC	Federal Energy Regulatory Commission
SMR	small modular reactors
GNP	gross national product
COCOM	Coordinating Committee on East-West Trade
CFC	chlorofluorocarbon
HFC	hydrofluorocarbon
EPA	Environmental Protection Agency
DOT	Department of Transportation
GHG	greenhouse gases
ESPC	energy service performance contract
ESCO	energy service company
MLP	master limited partnership
REIT	real estate investment trust
IRS	Internal Revenue Service
ARPA-E	Advanced Research Projects Agency-Energy
EFRC	Energy Frontier Research Center
PRG	Partnership for Responsible Growth
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change



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