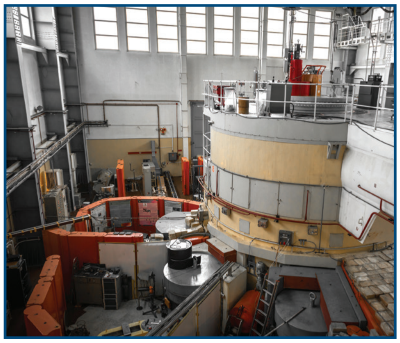
2016 FORUM ON THE FUTURE OF NUCLEAR ENERGY

The Future of Nuclear Energy in the United States



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FOREWORD

As has been the case since the Aspen Institute Energy and Environment Program (EEP) started in the mid-1970's, in the aftermath of the oil embargo, the program has been a place that convenes on tough issues at critical times and examines them closely. In early 2016, EEP began looking at issues around nuclear energy and its future within the US energy system. The last year in particular was a difficult one for the nuclear industry with several plants shutting down before the end of their lifetimes, and many more at risk of shutting down early. The 2015 climate agreement in Paris and the international goal of decarbonizing the energy economy means that the loss of low-carbon power sources is a setback for a nation seeking to accomplish that goal. With low natural gas prices, increasingly competitive renewables like wind and utility scale solar, as well as efficiency programs that keep the growth of generation needed low, nuclear power has been at risk for several years.

At the same time, the next generation of nuclear power is being developed, and there is promise on the horizon for both small modular reactors and advanced nuclear technology. But more federal investment is needed in advanced nuclear technology, both in research and development, but also in funding, testing and deployment, and in support for licensing first-of-a-kind technologies through the Nuclear Regulatory Commission.

To lead this conversation, we were honored to have Phil Sharp, former Congressman from Indiana and President of Resources for the Future, and Stephen Kuczynski, Chairman, President, and Chief Executive Officer of Southern Nuclear Company. Their intimate knowledge and experience with all of the issues addressed during the Forum as well as their skill and grace as moderators added greatly to the discussion.

The Institute acknowledges and thanks the Forum sponsors for their generous financial support. Without their support the Forum simply could not have taken place.

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Executive Director, Energy & Environment Program
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EXECUTIVE SUMMARY

Nuclear power in the United States is at a moment of existential crisis. If the present challenges are not addressed, then the future of nuclear energy may be far less promising and superior US nuclear expertise diminished.

Nuclear power plants across the United States (and some other developed countries) are in trouble, shutting down well in advance of license expiration, primarily for economic reasons. Small single-unit merchant plants are at particular risk, but all plants face challenges from low demand growth, low natural gas prices, subsidies for renewables, and increased operational costs. Nuclear plant retirements have serious regional economic and employment impacts; they also tend to increase reliance on natural gas, which in turn increases greenhouse gas emissions.

Sustaining the existing fleet preserves zero-carbon power in the near term, maintains the potential to add technologies to the installed base that could unlock several gigawatts of additional capacity, and paves the way for advanced solutions in the long term. Federal interventions to help the existing fleet could include tax credits or accelerated depreciation for nuclear, national carbon pricing, speeding up the evaluation and implementation of accident-tolerant fuels, and addressing price formation issues. Independent System Operators and Regional Transmission Organizations could start pricing more attributes of nuclear generation, implement a carbon adder and low-carbon dispatch, or let nuclear plants ramp to avoid negative-priced hours. Most of the important policy pieces are at the state level, where solutions could include clean energy standards, power purchase agreements, re-regulation, subsidization, or carbon pricing.

Climate change represents another pressing reason for new nuclear, as it is not clear that there are legitimate pathways to get to deep decarbonization that do not involve a significant expansion of nuclear power.

New build, meanwhile, is happening around the world, mostly in developing countries. In the US, the public generally supports nuclear power but is concerned about nuclear waste. In addition, policymakers looking at the over-budget, behind-schedule plants now being built cannot fathom a path to a nuclear renaissance. Still, there are pressing reasons to promote new nuclear in the US, including national security, nuclear safety expertise and climate. The list of countries building new reactors includes many with no experience operating them and is a bit scary from both a safety and a proliferation perspective. Russia and China could dominate enrichment capacity, are the leading vendors of current and perhaps future generations of nuclear technologies, and see nuclear power as an instrument of geopolitical influence. The US needs a strong domestic nuclear program to maintain its exceptional competence to address safety, threat reduction, and nonproliferation. Climate change represents another pressing reason for new nuclear, as it is not clear that there are legitimate pathways to get to deep decarbonization that do not involve a significant expansion of nuclear power.

A world without nuclear power would require an incredible – and likely unrealistic – amount of renewables to meet climate targets. The environmental community has to come around to the realization that pursuing deep decarbonization solely through renewables is very risky. There are several state and federal policy approaches that could promote new nuclear, but the case for new nuclear has to be made more clearly, more forcefully, and in a way that does not frame the solution as a binary choice between renewables and nuclear.

While there does not appear to be sufficient urgency or political will in the US to undertake the degree of mobilization of new conventional nuclear plants needed to pursue advance nuclear technology, advanced reactors that use new types of coolants, operate at different pressures and temperatures, or are smaller and more modular could represent the future of nuclear power. Advanced designs could reduce the footprint of a nuclear plant, reduce siting restrictions, reduce costs, vastly improve safety, and either produce less waste or directly consume waste as a fuel. Startups doing innovative advanced nuclear development are raising some capital, but the challenging time scales and dollar amounts involved in nuclear, as well as licensing uncertainty, make it hard to attract investment. It is imperative, though, to get small demonstration prototypes built in order to advance the technologies, retire risks, and allow investors, legislators, and others to see progress – and for most companies, that will require significant government support.

The Federal Government can help support advanced nuclear, such as through the technical, regulatory, and funding capabilities of the Department of Energy and its national lab partners.

The federal government can use loan guarantees and its purchasing power to invest in, advance, and expand the pool of private capital available for the next generation of nuclear power. It can also help support advanced nuclear in other ways, such as through the technical, regulatory, and funding capabilities of the Department of Energy (DOE) and its national lab partners. In fact, the newly created Gateway for Accelerated Innovation in Nuclear (GAIN) within DOE is intended to provide the nuclear community with better, more transparent access to those capabilities, including providing test beds and demonstration platforms to address sets of key technical challenges shared across many advanced nuclear technologies. Another key way DOE could provide support is by establishing an "X" challenge for advanced reactors at a certain cost per watt, as it did for solar under SunShot; if advanced reactors are going to get deployed, they have to be cost-competitive. Advanced nuclear also has rare bipartisan support in Congress, so measures to promote it might be able to move forward in the divided landscape following the November 2016 elections.

There are questions, though, about whether the Nuclear Regulatory Commission (NRC) is ready to review licenses from advanced reactors as they move closer to reality. Squarely focused on safety and security, the NRC is trying to shift its culture to be more risk-informed in order to remove unnecessary burdens that may be hindering nuclear development and innovation. NRC staff are trying to ensure efficiency, speed, and effectiveness in reviewing advanced designs, including by working closely with DOE and the industry to understand and prepare for advanced technologies, conducting faster technical and licensability reviews, and providing appropriate flexibility and exemptions from criteria meant for traditional light water reactors that are irrelevant to advanced designs.

Major takeaways and recommendations from the 2016 Aspen Institute Future of Nuclear Energy Forum included the following:

- **Nuclear power, while on the rise world-wide, is at an inflection point in the US. With the confluence of low natural gas prices, dramatically falling costs of renewable generation (partly caused by subsidies), and aging nuclear plants, less profitable nuclear plants are shutting down and being replaced by higher carbon-emitting natural gas plants.**
- **If the US wants nuclear energy to be part of the low-carbon equation, transitioning from renewable portfolio standards to clean portfolio standards will be an important step, whether this is on a state by state basis or through national legislation.**

- **More federal investment is needed in advanced nuclear technology, both in research and development, but also in deployment funding as well as support for licensing first-of-a-kind technologies through the Nuclear Regulatory Commission.**
- **The US nuclear industry has long set the standard for safety in the US and abroad. It is important that it continue to lead the world in having adequate protection of nuclear materials.**
- **No one power source, whether nuclear, natural gas, wind, or solar, can provide 100% of the clean power the US will need over the coming decades. Policy makers in federal and state governments should adopt a "yes, and…" mantra in order to achieve national goals.**

STATUS OF EXISTING NUCLEAR POWER PLANTS

Several existing nuclear plants are in danger of closing, primarily for economic reasons. Policymakers are beginning to grapple with whether and how to try to sustain the current fleet.

PROBLEMS FACING THE FLEET

The penetration of renewable energy remains pretty small globally. Of all global energy consumption, nearly 80% is fossil fuels, 2.5% is nuclear energy, and 20% is renewable sources, including hydro and wood-burning stoves. Only 1.4% is wind, solar, modern biomass, and geothermal power.

Nuclear power in the United States represents 20% of electricity generation, and nearly 2/3 of no-carbon, or clean, electricity.

Nuclear power plants in the United States (and some other developed countries) are in trouble. Nearly 20% of U.S. generation comes from nuclear power, and the U.S. nuclear fleet is split more or less 50-50 between regulated and unregulated assets. Of the 100 gigawatts (GW) of existing U.S. nuclear reactors, about 8 GW have announced an early retirement, and 47 GW are at risk financially. Only 22 GW are financially positive, while the financial status of another 22 GW is unknown, because they are in the rate base.

Plants are shutting down well in advance of their license expiration purely for economic reasons; where costs are higher than available revenues, nuclear plants are not economic. Small single units are most at risk, as they have fewer megawatts across which to spread costs. Some large single unit sites are shutting down 30 years before the technology would dictate. Large dual unit sites have more economy of scale, but even they are in jeopardy. The retirements and challenges are mainly affecting merchant plants, but plants in vertically integrated states are also at risk for not being competitive. Assuming a 60-year run life for existing generation, many more gigawatts of nuclear generation will retire within the next couple of decades (though some plants may get licenses extended to 80 years).

The combination of low or no electricity demand growth, low natural gas prices, continued and increased subsidies for renewables, and increased operational costs is creating real problems for nuclear plants. Nuclear plants get about 85% of their revenue stream from energy payments, which is more than other generation sources. The wholesale economics for merchant nuclear are challenging due to low natural gas prices, with forward prices in the $25-$40/MWh range. Prices are too low to sustain investment in nuclear plants – which could suggest that not all costs and benefits are being incorporated into the market. At the same time, the operating cash costs for nuclear generation have risen a lot over time, running way above inflation, leading to gaps between operating costs and prices.

Compared to the cost of new generation, relatively economic nuclear units are being shut down as new resources are added to the system, whether gas or renewables. At-risk nuclear is currently cheaper than new wind and solar, even subsidized, though renewables costs continue to fall. Renewables, however, are promoted by policies and subsidies that existing nuclear plants do not receive. For instance, many states have Renewable Portfolio Standards (RPSs) that aim to increase renewables in order to decrease carbon emissions – which may be having the unintended consequence of forcing nuclear power out. Furthermore, In PJM, nuclear power is the only zero-carbon technology that does not get rewarded with out-of-market payments; picking technologies and paying them different prices is antithetical to competitive markets, but it is the current reality.

Nuclear power, however, may not have the allies it needs to shift policies and market designs. Big industrial consumers, for instance, often do not see protecting nuclear power as being in their interests. Many think there will be low gas prices for a long time, so they do not see price volatility as a risk, and they are betting that there will be no comprehensive U.S. carbon policy for years. Similarly, nuclear sometimes lacks champions in governments. In California, for example, there has been no champion for nuclear, so whether it makes sense to do so or not, the Diablo Canyon nuclear plant will be closing as the state moves towards a distributed, community-aggregated future.

When a nuclear plant shuts down hundreds of people are put out of work and the economic impacts to an area can be devastating.

When a nuclear plant shuts down hundreds of people are put out of work and the economic impacts to an area can be devastating. As nuclear generation retires, there also tends to be greater reliance on natural gas, which means carbon dioxide emissions and the risk of price volatility increase.

Preserving the existing fleet is not merely about maintaining the status quo. For instance, there is huge additional potential in nuclear plants that is not far from being unlocked. There are technologies that can be brought to the installed base that can later carry over into the design of advanced reactors, including industrial internet and digital technologies, advanced simulations, and fuel cycle R&D (e.g., developing accident-tolerant fuels). Whether with new capabilities related to fuels, instrumentation, or general innovation in the fleet, it is not impossible to think that 15 GW or more of capacity could be added to the existing fleet, or that some plants could be extended beyond 60 (or perhaps even 80) years. It is cheaper to install upgrades than to build new capacity.

Keeping the existing fleet online should be framed as part of a long-term decarbonization strategy that preserves zero-carbon power in the near term to pave the way for advanced solutions in the long term (whether renewables, nuclear, storage, or something else). Using existing nuclear plants as a bridge to the end of the next decade, for instance, could save $30-$50 billion across the power system, allow continued deployment of renewables, and require fewer additional natural gas generation resources. Conversely, if the United States cannot maintain its existing fleet, it will have a hard time supporting new development or advanced reactors. Nuclear power has to survive the short-term to even have a chance of reaching the nirvana of the long-term. Nuclear is an industry with long lead times, and it is important to make sure that nuclear does not die on the vine between now and when humanity really needs it.

SOLUTIONS FOR THE EXISTING FLEET

There is a risk that the United States will lose 50%-60% of its nuclear fleet within a relatively short time frame, and yet the federal government, as a whole, has not really gotten involved to solve the crisis. The crisis facing the current nuclear fleet will not be solved, let alone new capacity built out, without federal policy solutions, preferably ones that benefit advanced nuclear as well, have willing champions, and could happen quickly. Congress, the Department of Energy (DOE), and the Federal Energy Regulatory Commission (FERC) could all play roles. Congress, for instance, could advance production and investment tax credits (PTCs and ITCs) or accelerated depreciation for nuclear. Congress could also advance national carbon pricing, though the intransigence of many Congressional Republicans and the waning but still considerable influence of the coal lobby (and to a lesser extent the oil and gas industry) breed pessimism that there will be any near-term action on a national carbon price (much less one high enough to actually address nuclear's needs).

While the current Congress is dysfunctional, and there is not enough time or political oxygen in the current session to get anything done, there will be a new Congress and Administration in 2017 that could be persuaded to take some kind of action to sustain the existing fleet. That persuasion has to be powerful and compelling, and it has to come from an organized coalition involving labor, business, utilities, national security experts, and others. (Coalitions are already starting to come together.) The arguments to Congress probably should not focus much on how nuclear plants provide baseload power and advance fuel diversity, as neither of those arguments is resonating well in DC. Other sources can provide baseload power (and looking into the near future, baseload may be less important than load-following, on-demand, dispatchable power), and national fuel diversity is actually increasing (with natural gas growing and coal shrinking).

Congress could advance production and investment tax credits (PTCs and ITCs) or accelerated depreciation for nuclear

The Department of Energy, meanwhile, has relatively few levers it can use to affect the problem. The Secretary of Energy has come around on the issue and is at least using the bully pulpit. One long-term development that could be a game changer for the existing fleet is the implementation of accident-tolerant fuels. Speeding up the evaluation and implementation of new fuels and peeling back regulatory requirements could fundamentally change the picture for the existing fleet. Pushing a more computationally intensive and faster regime for fuel evaluation would also later benefit advanced reactors.

There are also opportunities for FERC to play a leadership role in terms of how prices are structured in competitive markets. The pricing algorithms appear to be suppressing prices by about 10%. Addressing price formation issues will not solve nuclear's problems, but it will help create a healthier competitive wholesale market, which would benefit nuclear. As for carbon abatement, FERC lacks the authority to do anything to differentiate between power sources based on emissions intensity, but a bigger challenge may be that FERC may look to mitigate or otherwise interfere with state attempts to deal with climate change. There is already tension, with the Environmental Protection Agency (EPA) saying states have to address carbon, FERC saying they cannot, and one of the cheapest tools to do so (i.e., nuclear) being lost. This is a rocky time for wholesale markets and FERC.

Beyond the federal level, it is possible that Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) could provide partial solutions. They could start pricing the value of various attributes of nuclear generation, such as on-site fuel supply, voltage support, and fuel diversity. They could implement a carbon adder and low-carbon dispatch, but they likely will wait for state or federal policies that drive that (and would need approval from FERC). They can also let nuclear plants ramp to avoid negative-priced hours. In some markets, nuclear plants are not getting paid for power some percentage of the time; ISOs send out negative price signals in merchant markets when there is too much power on the system, which is a direction to ramp down. Intermittent renewable energy generators, because they get the PTC only when they run (in addition to state credits), will run through negative price events. (The fact that generators will run economically at negative pricing because of government subsidies suggests that the PTC should perhaps be reshaped into something like the ITC that is not dependent on producing megawatts.) Existing nuclear units could ramp (with some new instrumentation installed), and the French fleet ramps every night, but there is no market signal for it in the United States. Allowing nuclear plants to ramp will give them the benefit of getting paid nothing instead of losing money, which at least is a little better.

Most of the important policy pieces, however, are at the state level, and several states are exploring solutions. The problem is most acute in merchant markets, but the conversation will occur soon in regulated ones as well. Recent Supreme Court decisions have preserved lots of authority for states to act as long as they do not directly interfere with competitive markets. As long as they structure the support for nuclear right, it should be permissible. However, state regulators and legislators trying to advance a clean energy agenda generally will not do things that the local environmental advocates hate, so the regulators tend not to take on the nuclear fight. The only way action on nuclear seems to occur in states is when companies say they will shut down the plants and put people out of work.

The risk of job losses from plant shutdowns, for instance, is what led to the quick political win in New York, where the state included Zero Emission Credits in its Clean Energy Standard to support existing upstate nuclear plants. New York used the social cost of carbon and the relative carbon intensity of the state fleet to come up with a value for nuclear, then subtracted the Regional Greenhouse Gas Initiative (RGGI) price on carbon to arrive at a payment to nuclear in the form of Zero Emission Credits. The Zero Emission Credits are designed to help nuclear power be a bridge to 50% renewables by 2030; while only a temporary fix, this is still progress. The New York approach is one solution, but New York is a bit unique. It has its own ISO, and the Public Service Commission and Governor's office are marching together on this, all without legislation. In most states, legislation would be needed. Plants in New York are also far less economic than plants in some other states, which means plants could be easier and cheaper to save elsewhere.

State solutions could take many forms. Other states (e.g., Iowa) have quietly solved the problem with power purchase agreements (PPAs). Another option is re-regulation in competitive states, or a hybrid to regulate generation only. States could place a value on diversity and security of fuel, which would benefit nuclear over natural gas plants that rely on interstate pipelines. States committed to competitive markets could address the range of out-of-market subsidies, by getting rid of them or adding ones for nuclear. They could include nuclear under their RPSs (though renewables do not want to compete with nuclear). In addition, states could enact carbon pricing to help make existing nuclear units economic. Although existing carbon prices have not helped the fleet because they are too low, a carbon price as low as $16/ton could save existing nuclear plants, at least in some states.

There is a risk, though, that these incremental fixes – at whatever level of government – will be too little, too late.

BUILDING NEW NUCLEAR PLANTS

For climate and national security reasons, the future of nuclear cannot be framed around saving 50-year-old plants. New nuclear is essential. While a few new reactors are being built in the United States, though, the environment for new U.S. nuclear remains very challenging.

HURDLES TO BUILDING NEW PLANTS

After five years of learning the lessons of Fukushima, new build is happening around the world. The nuclear renaissance is mostly in the developing world. In the developed world, Fukushima did not change much; it was not building much new nuclear before Fukushima, and it is not building much after. It is very hard to build a nuclear power plant in a country that lacks a strong central government, or at least a strong developmental state; the history of nuclear development and commercialization around the world has been pretty top-down. The plants being built are mostly in countries such as China, Vietnam, Turkey, Jordan, and the UAE, and plants are desired in Saudi Arabia and former Soviet countries. None of those countries are democracies, and all have strong government involvement in building the plants. The UK is one democracy building new nuclear plants right now, as a strong majority in the UK is in favor of building nuclear.

In the United States, the general public generally supports nuclear power; Fukushima did not recreate an anti-nuclear movement the way some might have expected. Much of the decision making does not happen at a federal level. Financing, siting, and other practical issues regarding nuclear power all occur at the state level in the United States. Siting is a particular challenge for getting new nuclear deployed, partly because it takes a long time to characterize sites; it could be worthwhile for the industry to explore the opportunities for building on existing sites that utilities already have.)

U.S. policymakers and the American public are generally less informed with regard to nuclear energy than even to other sources of energy. To a degree, this is understandable, as not many people are intimately involved in the nuclear industry or with nuclear technologies. Many people don't care about the source of their electricity as long as their energy is cheap and safe. It is hard to get grassroots support, and it is unlikely that the public will focus on nuclear energy in a good way. At public meetings, people have an exaggerated view of the safety implications of an accident. Fear of radiation is a bigger problem than radiation itself, and both the public and policymakers need to be educated about the extremely low risks associated with nuclear power. Since the 1970's there have only been three nuclear incidents that were rated 5 or higher (on the International Atomic Energy Authority's scale of 1-7) Chernobyl (USSR), Three Mile Island (US-Pennsylvania), and Fukushima (Japan). The Nuclear Regulatory Commission (NRC) has done consequence modeling and has a lot of information that could be useful.) The industry may exacerbate the problem by being overly cautious and calling things emergencies that are very low-level, which unnecessarily scares people. If the airline industry acted like the nuclear industry, no one would ever get on a plane. Nuclear power is attacked for its safety, cost, and impacts, yet all forms of energy have impacts.

The industry needs to get its social license to operate back, and a lot of that involves the perennial policy problem of nuclear waste. The challenge posed to the industry by nuclear waste is real, in terms of politics, public opinion, and substance. The industry will not generate political and public will to build lots of new nuclear capacity unless it can show to policymakers and the public that there is a plan for waste. Yucca Mountain is not going to happen, as the Department of Energy has moved away from it to a consent based approach this year. Figuring out the transportation, storage, and disposal of waste is just as important as nuclear technology development. This is the reality the industry has to face.

The current fleet consists of Generation II plants, and Generation III+ is basically a way to incrementally improve on Gen II. Policymakers, however, look at the cost of building AP1000s in the United States now and cannot fathom a path to build more (at least outside some regulated utilities). Even with advanced light water designs, they reasonably are unable to see a path to a nuclear renaissance. Some passive safety features and modularity are not convincing in terms of the realities of getting these plants built.

The reality is that nuclear power is growing worldwide. The only question is whether the United States has a significant role or not.

Reactors being built are often dramatically over budget and behind schedule. Building an AP1000 in the United States costs around $6000/kW, with the equipment accounting for about $1000-$1100 of that; in China, those components cost only a little less (around $900/kW), but the finished plant costs only $2000-$2500/kW. The difference is not the cost of the equipment, but rather all the other costs for putting the plant together (e.g., controlling the schedule, labor costs, and construction costs). Nuclear power is expensive and slow to build in part because the U.S. reactors being built now are not reactors born out of a mature nuclear industry; given the length of time since reactors had been built in the United States, the industry is, in effect, starting over. There is a need to find ways to speed things up in the United States, such as through standardization and improved licensing. The United States does great in contracting for, delivering, and building combined cycle gas turbine (CCGT) plants, as those are built offsite and can be built in a very narrow cost and schedule band, and the United States needs to find a way to make nuclear more like CCGT. In the meantime, new nuclear is basically only being built in regulated markets, where a regulator body can approve the investment; in competitive markets, no one has any idea what market conditions will be in 5 years, let alone 10 or 15 years, and no one is looking at long-term objectives or policy. There do not appear to be any more Generation III+ plants on the horizon in the United States, but the country will miss a huge opportunity if the current plants are the only ones it builds; the supply chain will dry up again, and the country will once again start all over.

NATIONAL SECURITY & SAFETY ARGUMENTS FOR NEW NUCLEAR

Perhaps the foremost policy issues concerning nuclear power are assuring the safety and security of nuclear plants around the globe and preventing proliferation of weapons-applicable nuclear materials.

There is a collective interest in ensuring that no major nuclear accidents happen anywhere – as major incidents anywhere affect nuclear power everywhere. One more Fukushima anywhere in the world and the entire nuclear fleet – existing and future – will suffer. The list of countries building new reactors, however, includes many with no experience operating them. The list is also a bit scary from a national security perspective. Any nuclear buildout has to be carried out responsibly, which argues for the United States being a leader on safety, security, and nonproliferation.

The United States has been the global leader on nuclear science, safety, and nonproliferation, but its influence has decreased dramatically in the last few decades. In October 1973, the United States went from 27% dependence on foreign oil to 35%, and it was a national crisis. In the mid-1970s, the United States had big turnkey nuclear projects, reprocessing, enrichment, and so forth. The United States was a major global nuclear player. The United States, however, has gone through a transition from zero dependence on foreign uranium in 1985 to overwhelming dependence in 2015, and unlike with oil, there has been not a whisper of protest. The United States is falling far behind in enrichment capacity and in uranium mining. Russia, meanwhile, sees nuclear energy (along with natural gas) as a way to win back Eastern Europe; it is consciously using nuclear as an instrument of geopolitical influence. Russia just committed to building 11 new plants before 2030, and its nuclear order book is $300 billion, much of it self-financed. Hungary had Russia build its big nuclear plant because Russia would give them the money to build it. The same happened in Jordan. China is right behind Russia in using nuclear power for geopolitical influence. If China takes over European enrichment, then China and Russia together would control 90% of global enrichment. If the United States is not careful, the Chinese market domination seen with solar PV will be repeated on nuclear.

The United States is falling far behind in enrichment capacity and in uranium mining. Russia, meanwhile, sees nuclear energy as a way to win back Eastern Europe; it is consciously using nuclear as an instrument of geopolitical influence.

This should be cause for concern in the US. In terms of both non-proliferation and commercialization, it is doubtful that it is in the United States' best interests that Russia and China are likely to be the leading vendors of current and perhaps future generations of nuclear technologies for many developing countries that are interested in becoming civilian nuclear nations. It is not clear that the United States can lead the world from the rear. Threat reduction and nonproliferation are hard to do successfully if the United States lacks a domestic nuclear industry; the country needs a strong domestic nuclear program to have a credible seat at the table for nonproliferation. If the country has a sliver of the industry and none of the fuel cycle, it will not even be at the table. It is impossible to quantify those benefits, but they exist and are important.

The reality is that nuclear power is growing worldwide. The only question is whether the United States has a significant role or not. If not, there is no one with better nonproliferation standards than the United States. Under the Atomic Energy Act of 1954, for the United States to export major nuclear materials or equipment, the host country has to live up to nonproliferation norms. Extra requirements were added in the 1970s. For the United States to get involved in a major reactor deal, much less a fuel cycle deal, a Section 123 nuclear cooperation agreement has to be in place. The United States dragged the rest of the world to the best nonproliferation standards, and it has to maintain that role of exporting and spreading the best practices of nonproliferation. The United States should be aggressively promoting Section 123 agreements. The United States could also promote an Assured Nuclear Fuel Initiative, to tell the world that it can rely on the market and the United States for assured supplies. In addition, there may need to be innovations in business models, technology models, and regulations to help U.S. companies promote nuclear power around the world.

The more that nuclear power can be moved from just being an energy issue to being a national security and foreign policy issue, the better its prospects will likely be.

CLIMATE ARGUMENTS FOR NEW NUCLEAR

At the UN climate negotiations in Paris in late 2015, the nations of the world agreed to set a goal of limiting warming to well below 2°C, and 1.5°C if possible, above preindustrial levels. Analytically, if there is a need to drive toward deep decarbonization, it is not clear that there are any legitimate pathways to get there that do not involve nuclear power.

The world is now about 0.8°C above preindustrial levels, or more than half way to the 1.5°C goal. Based on the fossil fuel infrastructure that is already built, the world is likely locked in to at least 1.5°C. The current trajectory suggests a world of 3-6°C. Keeping temperatures below even 2°C will be really hard to do. For a 50% chance of staying under 2°C, the emissions trajectory involves a slight uptick and then a sharp downward glide path, going into the negative emissions range. World energy demand, however, is going way up, and projections have consistently under-predicted non-OECD demand. Electric vehicles and increased desalination could greatly increase energy needs in developed countries, and India, China, and Africa will see huge increases in energy demand. That energy demand will be met, and the larger the energy demand, the greater the climate challenge.

The range of initiatives underway at all levels of government and in the private sector get humanity nowhere near the needed climate targets. If one adds up all the Nationally Determined Contributions (NDCs) pledged by countries under the Paris agreement, the world is still well short of where we need to be to avoid 2°C, even if every country implements their contribution fully; but it is a good start and the best option on the table.

If the goal is really to aim for zero, the renewable portfolio approach might lock humanity into a route that will prevent achievement of deep decarbonization.

The NDCs slow the rate of increase, but they do not bend the curve down. Nuclear – a lot of it – is needed to help close the gap, and it need not be limited to the electricity production slice of the energy picture. Electricity accounts for 41% of global emissions, but industry accounts for another 20%. A large amount of the energy requirements for industry are for production of steam, which nuclear could provide.

Today's nuclear capacity is around 390 GW, but the International Energy Agency (IEA) says 900 GW is needed by 2035-40, while the Pacific Northwest National Laboratory (PNNL) says the figure is around 1,614 GW. To meet the PNNL target, the world would need to build about 61 GW of new nuclear per year (or about 25 GW per year to meet the IEA target). Peak global additions, from 1980 to 1990, were around 20 GW a year, which is not totally out of range with the IEA. In 2015, however, about 9.4 GW of nuclear were added. Nuclear has deployed quickly in places in the past, though; the intensity of the nuclear build in France in the 1980's and 90's shows that a nation that puts its mind to it can make a lot of nuclear gigawatts happen.

It is important to remember that the PNNL's 1,614 GW figure is just the down payment, as it is a figure for 2035. It is not the end point, particularly if global energy demand ends up being much higher. The industry needs to be thinking in the 2,000-3,000 GW scale, or perhaps a reasonable starting place is to assume the need for a 5,000 reactor world by mid-century. Climate change is a massive problem, and aggressive targets are needed. The industry and policymakers should figure out what pieces, capabilities, and investments need to happen now to deliver that kind of capability. Everything has to be considered, from how plants are developed and sited to how long it takes to get them permitted and built to how supply chains will work. Reaching this level of nuclear build will require coming up with better core designs and business models; doing more of what the industry has been doing but a bit faster will not get the job done.

A world without nuclear power requires an incredible – and likely unrealistic – amount of renewables to meet climate targets. The capacity factor of renewables is much lower than nuclear, so much more has to be brought online. Whereas nuclear would need to grow 4 times over the current install, wind would have to increase 400 times – leaving aside the need for backup capacity and storage. Just in the United States, going 100% wind, water, and solar would require 72 offshore wind farms per coastal state, 50 large wind farms per state, wave platforms equivalent to 25 large nuclear plants, and enormous amounts of solar (which also requires storage and backup generation). Wind and solar also fluctuate not only daily but also seasonally (i.e., the wind in California does not blow much in winter), and there is no storage that can fill that gap. In addition, deep decarbonization with today's commercially viable renewables is a high-cost route – much more expensive than the incremental energy system costs of pursuing high levels of nuclear.

Furthermore, if renewables are the only favored decarbonization tool then emission reductions hit a dead end at around 75%-80% unless the system gets hugely overbuilt. The build out will either hit a price tolerance limit or a capacity limit. If the goal is really to aim for zero emissions (which science indicates is needed, though it is not yet really enshrined in federal and state policies), the RPS approach might lock humanity into a route that will prevent achievement of deep decarbonization. Deep decarbonization suggests a different path may be needed that deploys a wide range of approaches, not all of which are currently the cheapest options. Without advanced nuclear, carbon capture and storage (CCS), carbon removal, or technologies that do not exist now, the United States will not get anywhere near total decarbonization.

The environmental community, which has a fair amount of influence over electricity system policies, has to be gotten off the notion that deep decarbonization can be achieved solely through distributed energy resources (DER) or with just solar, wind, and energy efficiency. Some individuals within environmental groups are able to have that conversation, but it is not clear the institutions are quite ready for it yet. Those organizations fundraise through direct mail to people who are anti-nuclear and through grant requests to foundations that are anti-nuclear (or at least think that doing things around renewables, DER, and electric vehicles will solve the climate crisis), and so far they are mostly unwilling to stand up and talk about nuclear in a way that is credible. Some philanthropies, however, are starting to come around on the idea that deep decarbonization requires nuclear power and are beginning to recognize the limits of renewables, realizing that states and countries blazing a path that relies on renewables are doing so at great cost and in a way that is not a credible model for developing countries looking to climb the development ladder. While one cannot prove a negative, and some professor somewhere will come up with a theoretical case that it is possible to get to deep decarbonization solely with renewables, such an approach to deep decarbonization is very risky. There has to be a stronger initiative to reach out to big funders and the leadership of big green groups about how hard deep decarbonization is. It is not about being against energy efficiency and renewables, but rather that there is a high risk that deep decarbonization cannot be achieved with them alone.

One could argue that nuclear power is the most environmental source of energy (in terms of carbon footprint, land footprint, etc.), yet the dominant message is that environmentalism and nuclear power are opposed. Some renewables advocates have a kind of religious opposition to nuclear power. To a degree, this stems from a concern that nuclear crowds out renewables, but the conflict goes way deeper and way farther back. At the beginning, clean energy advocates were not focused on decarbonization; the vision was always anti-nuclear (and anti-fossil) at its core. From a carbon reduction perspective, however, both renewables and nuclear are needed. There is a need to get away from fratricide between renewables and nuclear – and, for that matter, CCS for fossil. There can be more progress and a broader conversation if it is framed as renewables and nuclear. The zero-carbon goal can be a key driver for finding common ground.

POLICY OPPORTUNITIES TO PROMOTE NEW PLANTS

There has to be a sense of urgency to figure out a range of nuclear power policy issues, as policies and support are needed immediately. From a national security perspective, other countries are moving quickly on nuclear. From a climate change perspective, significant emission reductions need to happen quickly to achieve deep decarbonization. Somehow, a pathway forward is needed. This could involve pricing carbon, making reactors cheaper (e.g., by bringing down costs of construction), figuring out the financing (e.g., getting new authorities for DOE loan guarantees), creating markets (e.g., through nuclear portfolio standards or PPAs), facilitating access to global markets (e.g., simplifying export control restrictions, doing more 123s), or many other potential routes.

One possible route, for example, could involve states looking at baseload nuclear plants as part of infrastructure – investing in gas pipelines to support gas plants, lots of transmission and distribution to keep up with the intermittency of renewables, and nuclear plants as baseload. (That argument, however, has been unsuccessful in places; Massachusetts, for instance, chose to do nothing with nuclear, import power from Canada, and subsidize gas pipelines and renewables.) Similarly, at the federal level, it is conceivable that nuclear plants could be rolled into a big infrastructure legislative package. Both sides agree that there is a need for big infrastructure investment over the next decade, and while infrastructure packages have not historically paid for wires or pipelines (because they can be financed in the private sector), Congress is not prone to consistency and coherence, so there may be an opportunity to get a piece of the infrastructure package for nuclear. The 2009 stimulus provided lots of funding for infrastructure, including the grid, renewables, and distributed energy resources, and a new package could go further. Congress makes compromises by addition, not subtraction, and things can be added to bills that seem unimaginable beforehand. In addition, when the ITC is reviewed to address geothermal and others left out of the extension agreed to at the end of 2015, there will be an opportunity for the nuclear industry to push to be allowed to participate in those tax credits.

Getting state or federal policy action to support new nuclear generation, however, requires making the case more clearly and forcefully. The national security argument for nuclear power seems to be landing well (at least in DC). The climate arguments do not seem to be landing as well, given the polarization around climate change, the failure to consider what will be needed for deep decarbonization, and the tendency to look more at what is being built (i.e., the growth of renewables) than at the installed base (i.e., the actual penetration of renewables). In Congress, the strongest defenders of nuclear power are often climate deniers, while the strongest advocates for climate action have a history of hating nuclear power – though a bit of a generational shift is starting to occur on both sides. At the state level, policymakers (more or less of both parties) tend to support clean energy, but arguments that nuclear power is carbon-free and clean do not seem to penetrate. Low prices and fast construction times for most renewables and gas projects mean they can get done in the short time horizon of state policymakers, who tend not to contemplate longer-term risks. There is also a massive lobbying effort pushing the clean energy trend and the DER trend; clean and small sells well at the state level. Despite the fact that accounting for renewable energy subsidies is necessary for a true apples-to-apples comparison of economic competitiveness, math and being right do not win political arguments; people have a cognitive bias about renewables, and the trend in the United States is to accept renewables and hope that storage and innovation will address the gaps. Trying to promote nuclear at the expense of renewables is a losing proposition. On the other hand, with states moving to 50%-70% RPS targets, it may be impossible for nuclear to avoid fights with renewables.

The argument has to be made clearly to policymakers that it is not a binary choice. A technology-neutral low- or zero-carbon portfolio standard, for example, could eliminate the need to re-litigate the old arguments about nuclear versus renewables, while helping to save the existing plants, raise the statutory bar for energy of any type, focus on the long-term decarbonization challenge, and pave the way for having some market and statutory pull for advanced nuclear technologies as they come online. When President Obama proposed a national Clean Energy Standard in 2011, which included nuclear and CCS, it landed in Congress with a thud. If it is brought up again in the next Congress in the right way, it could theoretically bring renewables advocates, environmentalists, the nuclear community, labor, and business together to support it. NGOs focused on environment, non-proliferation, and global development are already working in coalition on how to communicate better across organizations advocating for civilian nuclear energy.

ADVANCED NUCLEAR

There does not appear to be sufficient urgency or political will in the United States to do a French-style, top-down, centralized mobilization of conventional nuclear plants. The mid-20th-century top-down model of nuclear deployment is likely dead. There is a need for a transformed nuclear sector that is innovative, networked, bottom-up, and decentralized. Government can be a catalyst and enabler, but companies will have to try more designs and technologies to figure out what works. Nuclear, however, is a conservative, risk averse industry by nature. To get advanced reactors on the stage in time to have an impact, the industry will have to figure out how to innovate faster, how to line up funding, and how to get the right kinds of government support.

UNDERSTANDING "ADVANCED" NUCLEAR

People within the industry see the distinctions between current nuclear and advanced nuclear, but the general public still generally thinks of nuclear power as 1950s/60s technology. The first commercial nuclear plant was in 1957. Many nuclear technologies were investigated at the time, but light water reactors took hold as military technology was adapted for civilian use in commercial power, and light water reactors are still the designs in use. The technology is fine, but it is old.

One can split hairs over the definition of "advanced" nuclear, but the term is generally used to encompass reactors that use new types of coolants (besides light water), operate at different pressures and temperatures, or are smaller and more modular versions of light water reactors. Some advanced reactor technologies are close, while others could be decades away. Within these designs, there are scientific breakthroughs on material engineering that can be brought to bear, including with regard to cladding, fuel, and coolants. Cladding materials (e.g., carbon composites, ceramics, coated metal) can provide huge advances in the thermal margin for safety. There are high-density fuels that could allow for more compact, modular reactors, as well as liquid fuels that could allow for higher fuel utilization. There are numerous coolant materials that can be used, such as molten salt and sodium.

The public, policymakers, and philanthropies generally lack understanding about what the advanced technologies can do. New technologies and designs could reduce the footprint of a nuclear plant, reduce siting restrictions (e.g., no need for proximity to water), and change safety equipment and protocols. A key feature of some of the advanced designs is that they involve new ways of dealing with the problem of nuclear waste. Some are pursuing higher burnout designs, so there is less waste in the first place. Others are directly consuming waste as a fuel, reframing nuclear waste as a resource – and a slightly used one at that. The thousands of fuel bundles that exist have used about 1% of the energy value they hold, and they have to be stored for 100,000 years. Other countries reprocess waste and extract a little more, getting maybe to 2%-3%, after which the waste has to be stored for 10,000 years. Recycling waste enables extraction of 99% of the energy and leaves waste that only needs 300 years to get back down to regular levels. In Generation IV reactors, waste can be an opportunity, not a liability.

Small modular reactors (SMRs), meanwhile, are light water reactors. The theory behind SMRs was that they would be more amenable to a declining curve in construction costs due to being factory-built, so they could get quickly past the first-of-a-kind costs, but SMRs are still very much at the first-of-a-kind stage. SMR's prospects are at a critical phase, but it is not a good time for that to occur. For example, some SMRs could theoretically advance from feasibility to execution/decision within the next couple of years, but in an environment where it is incredibly hard to sustain an existing plant, there is no math analysis to justify committing to SMR construction. There is no demand growth pushing them, and natural gas prices are (and seem likely to remain) very low. The financials will drive SMR decisions, and the financials are not great. It will be challenging for SMRs to get over that first-of-a-kind hump, move rapidly down the cost curve, and get close enough in cost to other sources that its other attributes (e.g., load following) can come into play. There is a risk that the business prospects of SMRs will never even get a chance to be tested, and the SMR option may recede from the list of future possibilities unless some effort is made to prevent that from happening. DOE does have a program, though, to promote the accelerated deployment of SMRs by supporting design certification and licensing, and it is investing in SMR design and partnering to do early site work. DOE's timeline is to get SMR projects deployed by the mid-2020s, and it will be important to stick the landing on at least one of those projects in that time frame to demonstrate the value of the technology and to provide a pathway to true Gen IV technologies.

Advanced nuclear is generally used to encompass reactors that use new types of coolants (besides light water), operate at different pressures and temperatures, or are smaller and more modular versions of light water reactors. Some advanced reactor technologies are close, while others could be decades away.

STARTUPS, INNOVATION, & PROTOTYPES

While the United States has been relatively dormant for a long time in terms of building new nuclear, there is tremendous capacity and innovation in the national labs, major companies, and startups. Nuclear startups are good for the industry and are different from traditional companies and national labs in important ways (though players at all points of maturity in the market have an ability to contribute). Most startups are doing product development, not just technology development, and most are looking at Gen IV.

It can be very hard for nuclear startups to find the right people – people with passion and a skill set who can contribute in a startup environment – and that is a huge rate limiter on innovation. One of the key factors in advancing innovation in any industry is having a group of talented people that have the same priorities and culture of work, backed by funding and a sense of urgency. People who are overly negative, not bought into the goal, or lacking the requisite skills can slow progress, while the best people can produce far more than others. Nuclear startups are overwhelmingly made up of young people, the vast majority of whom are motivated by a sense of environmentalism and stewardship and an awareness of the need for nuclear alongside wind and solar if humanity wants to avoid the devastating effects of climate change. These young people often have strong technical backgrounds. However, there is a massive talent problem coming in the nuclear industry. To address it, DOE has to continue to sponsor programs at universities, the national labs need to start hiring not only PhDs and grad students but also undergrad interns, and the industry needs to do a better job of sharing success stories that can excite and entice students and help them realize that new generations in nuclear research are standing on the shoulders of giants.

It is useful to have a robust and growing sector with people rapidly investigating many types of Gen IV nuclear technologies using private capital and driven by the business case and market performance. In any technological industry, setting an expectation of striving for products that are 10 times better than what is in the market means that talent, people, and money are directed to things that could succeed in the market. It also makes sense to take on the biggest risks first, to ensure people's time and money are not wasted. Investors want to see staged investment with clear decreasing risks. If the products fail, though, then they fail. The philosophy of failing early and often is important to have in the nuclear innovation ecosystem.

Nuclear startups are raising capital, but most are not raising nearly enough. There are four dozen or more advanced nuclear startups in the United States and Canada, which have raised $1.6 billion. Many of the advanced reactor startups are funded by venture capital and angel investors. Some private investors are eager to get into the game of supporting the best power plants the world has created, but in general, it is hard to find investors willing to contemplate the time scales and dollar amounts involved in nuclear startups. More investors are needed that are willing to meet startups halfway with different fund structures and different timelines for returns. Investors who have made big aerospace investments may be good targets, as aerospace involves roughly comparable timelines and dollar amounts. Another good target could be private sector companies that have a bit of a philanthropic perspective on R&D, many of which have deep pockets, understand technology, and have a desire for more clean energy but have no idea about what is going on in nuclear or what advanced nuclear can do. The nuclear sector has to develop a better case for why advanced nuclear technologies would have profound impacts on the many things these private sector companies care about. These companies are very conscious of their brands, however, and they are unlikely to make a major investment (or do a PPA for nuclear power) unless it involves a new, exciting, cool technology.

It is hard to find investors willing to contemplate the time scales and dollar amounts involved in nuclear startups.

While licensing uncertainty makes it hard to make the investment case for a demonstration reactor, it is imperative to get small demonstration prototypes built. Building them advances the technologies, retires risks, and allows investors, legislators, and others unaware of what is happening in nuclear to see progress. Having something actually built that investors can see helps raise capital. Psychologically, people make emotional decisions, and having machines that are visible and cool makes everything else easier. The first plant is always more expensive, as a company has to prove out not only the technology, but also the manufacturing, operations, and service – elements that can only be learned by working on the real equipment, not through computer simulations. For startups closest to having a commercial design, it need not cost very much to get first-of-a-kind commercial prototypes built. Some could build small prototypes for $100-$300 million, which could plausibly be raised solely from private capital. For others, the cost could be $1 billion or more, which is not necessarily a lot, but for proof-of-concept prototypes, some kind of significant government support (e.g., cost-share, shared risk) is probably needed. For a commercial plant, it could be feasible to build without significant public cost-share if there are revenue streams from the prototype and the design can be licensed out for a bigger facility – but even if there is not a way to get power sold from the first-of-a-kind plant, there still have to be ways to get those kinds of plants built.

Having adequate (or, ideally, extra) funding can reduce the risks involved in building a demonstration facility. The most serious engineering risks have already been dealt with in the design, but there are always problems that arise that are not inherent to the technology. Those risks are reduced if a company has the funding to stick it out through the testing. If companies had double or triple their budgets, they could get to the end of the process and make everything work; it may be the best risk insurance possible, though very few projects have the luxury of that kind of budget cushion. Risk is increased by having too little capital and too ambitious a schedule. With the right funding, though, some prototype products could be up and running within 8-10 years, which is not too far out.

GOVERNMENTAL ROLE IN ENERGY INNOVATION

The federal government has had and continues to have an indispensable role in technology innovation, including energy innovation. There are three main reasons for this. First, private companies cannot capture the full economy-wide value of new energy technologies, and as a consequence, tend to under-invest in R&D relative to the benefits produced. Second, the longer-term the R&D investment is – and nuclear is very long-term – the less likely it is that private companies will choose it compared to shorter-term and more incremental opportunities. Third, the magnitude of viable energy technology investment is bigger than in many other industries – and nuclear is among the most capital-intensive within the energy sector, with a risk-reward profile that rarely attracts sufficient private sector inv estment. There is sometimes a debate that positions government investment in innovation and investment in deployment as a binary choice, but that is unhelpful and inaccurate; the two are symbiotic and mutually reinforcing, as deployment yields technological learning that feeds back into R&D, improves performance, lowers cost, and increases deployment.

The historical record of government's role in energy technology innovation is sometimes misunderstood or willfully ignored by some stakeholders and by Congress (which has to appropriate money that enables the government to play that role). For example, assertions that horizontal drilling and hydraulic fracturing are proof that industry can solve energy challenges alone ignore the fact that those technologies were developed over the course of the 1970s and 1980s by the federal government, working with industry, making targeted investments that the private sector would not make, which then took decades to come to fruition. That tends to be the cycle of time in energy. The DOE loan guarantee office also played a critical role in the story of the solar industry's growth over the past several years. In nuclear, the U.S. government, particularly the Navy, worked with industry to demonstrate light water reactor technologies in the 1950s and 1960s. DOE work with industry in the 1980s led to the certification of dry storage casks. In the 1990s and 2000s, government programs led directly to the construction of advanced boiling water reactors and AP1000s. The historical record, recent and distant, demonstrates that the federal government role in energy innovation, particularly nuclear, is critical and is done best in partnership with the private sector. The U.S. government can and must do a better job in working with private actors, but there is no realistic scenario where the private sector alone can successfully develop next generation reactors.

GOVERNMENT FINANCING FOR ADVANCED NUCLEAR

The Department of Energy is the federal government's primary driver of nuclear innovation, supporting it at each stage of technological and commercial maturity. The role of government in many ways is to do de-risking, particularly in ways that are understandable and consumable by the private investment community and address investor concerns. There needs to be a policy conversation about whether DOE has the right tools to promote innovative nuclear technology development and deployment.

Money, of course, can be a key form of governmental support. Substantial direct investments to bring individual plants online are unlikely. Even in the 1970s, when there was lots of government money around nuclear during the Cold War, there were not enough resources to bring multiple technology options to the point of development and deployment. There are other steps the government can take, though. For example, it can invest in breakthrough R&D, though ARPA-E is still trying to develop an appropriate scope and role for a nuclear program. The government can also do cost- or risk-sharing. From a VC perspective, the government could provide some kind of matching funds, similar to the Small Business Administration loan program, where the private sector provides the first-level vetting, and if criteria are met, the government provides matching funds as a grant or loan.

Loan guarantees are one of the main routes that can help expand the pool of private capital available, though there was trouble getting loan guarantees out the door last time. DOE loan guarantees have helped the construction of Vogtle, but that is about it, so it is conceivable that new legislative authorities are needed, which should be on the table for the new Administration and Congress. In addition, a company going for a loan guarantee is like going into a multi-year boxing match, with lots of give and take over a long time and with great uncertainty about actually getting to the end point. It would be better to have a template up front that lays out what criteria companies have to meet to get the loan guarantee.

The federal government can also use its purchasing power to invest in and advance the next generation of nuclear power, including through guaranteed markets, like what NASA did for the development of the private space industry, as well as power purchase agreements. The government's purchasing power could de-risk nuclear technologies enormously for commercial lenders; PPAs allow a demonstration project to be treated under project financing, and once a class of assets is up and running, they can be pooled and securitized, which lowers the cost of capital even more. DOE, the Department of Defense (DOD), or any other government agency could sign on to be customers of the power from advanced nuclear reactors. DOD has 30-year PPA authority, generally has large defense budgets to work with, and would like power sources that are resilient if the grid goes down (so bases can still meet mission requirements); various branches of the military could be interested in supporting small nuclear power demonstration projects. DOE, meanwhile, has 10-year PPA authority (with the exception of Oak Ridge). PPAs can be tricky for the national labs, though, as they can buy power for their sites at normal market rates, but some entities that fund activities at labs are not interested in paying a premium for power from a first-of-a-kind reactor design.

Under any of these types of financial commitments, there has to be a way to tie the commitments to the achievement of technical and financial benchmarks by developers, especially if there are many players and designs. Similar to shale, there is a need to set up a structure in which long-term innovation and partnership between the public sector and private developers can succeed in ways that are unanticipated.

There is also a need to make such financial commitments possible, as DOE is extremely budget-constrained. The federal budget is $3.8 trillion, and the government spends a ton of money on many things (e.g., weapons systems), yet in dealing with what the President has defined as the biggest problem facing mankind – climate change – the industry is struggling to make the argument that the government should adequately fund ways to use nuclear power to help solve the problem. The money could be there if the merits justify it and the politics work; the renewables PTC approved by Congress in late 2015 is about $3.5 billion per year. However, if Republicans retain the House (much less take the White House), it is likely that budgets will stay tight.

NON-FINANCIAL GOVERNMENT SUPPORT FOR ADVANCED NUCLEAR

Many of the ways the federal government can help support advanced nuclear are less explicitly financial. In June 2015, the White House convened a meeting to discuss advanced nuclear innovation, and a direct outcome was the rapid creation of the Gateway for Accelerated Innovation in Nuclear (GAIN), which is essentially a startup within DOE. The intent of GAIN is to provide the nuclear community with better, more transparent access to the technical, regulatory, and funding capabilities of DOE and its national lab partners to move advanced nuclear technologies toward commercialization, while also providing support to the existing fleet. GAIN has made some strides, such as setting up a single point of access for the advanced nuclear community to help them navigate federal capabilities. It also awarded small business vouchers to some advanced nuclear startups to catalyze ongoing collaboration between the startups, the national labs, and DOE. GAIN is still figuring out the public-private partnership model but is trying to find a more integrated, as opposed to sequential, approach to innovation that gets public and private dollars supporting development, demonstration, and deployment of advanced nuclear technologies. A lot of GAIN is still formative, but it is making progress.

One of GAIN's goals is to provide test beds and demonstration platforms for advanced nuclear R&D. It is important to get prototypes built – and the government could make sites available in remote places – but before that step can happen, there have to be test beds; companies can only invent and innovate as fast as they can test. GAIN conducted a study with some national labs on advanced reactor test and demonstration platforms, and there is an active conversation occurring in the Administration on how to provide platforms that are useful without picking winners (though any of these platforms will involve much more money than the Office of Nuclear Energy has in its budget, so funding will have to be proposed and appropriated, which means the next Administration and Congress will have to be convinced that these test and demonstration platforms are worth the investment). Test beds actually already exist, for the most part, as the labs have nearly all the necessary capabilities for the early stages of technology R&D, but the challenge is to figure out how to provide better access and flexibility. There is a nuclear infrastructure database that has all the capabilities of the labs and universities, as well as a gap analysis study of the capabilities that are lacking.

To support advanced nuclear, there is a need for public support to address sets of key technical challenges shared across many advanced technologies, such as issues related to materials and fuels, and GAIN is trying to figure out how to address those kinds of common technical needs. Test reactors that could test lots of different designs could be useful. Universities and national labs make up the test reactor ecosystem, but while they have machines with thermal neutrons, the United States lacks fast neutrons (one has to go to Russia for that). Having a domestic resource for fast test reactors would be valuable for speeding up the process of materials development for advanced reactors. With regard to fuels, the model for fuel qualification is antiquated and is hindering innovation. It takes 15-20 years to qualify a new fuel design, but computer capabilities with regard to modeling and simulation could cut that in half. The government has already invested in developing software tools for modeling and simulation for light water reactors, and it would be a logical evolution to add functionality for other sorts of reactors and technologies. Minimizing experimental needs can fundamentally accelerate innovation in many ways.

If GAIN is made real, it will help formulate a coherent program to make DOE's resources available to developers of new technologies on useful terms and make sure there are mechanisms for communicating DOE-wide about what is available to assist nuclear entrepreneurs. There are good opportunities currently underutilized by industry. For example, DOE also has a Nuclear Energy Enabling Technologies (NEET) program that provides about $14 million each year for competitive cross-cutting R&D. DOE also has a Nuclear Science User Facilities (NSUF) program that is open to industry, provides cost-free access to capabilities, and typically has expert staff that can provide assistance. Many people do not know about NSUF, and there have been only a handful of industry applications. To get that cost-free access ($5-$6 million worth of testing), there has to be funding in the user facility for work of the nature the applicant wants to do, and applicants have to be willing to publish the results from the work, making the resulting data freely available in the open literature. Technologies can still be proprietary as long as the results of the work are freely shared. (The innovation literature makes clear that knowledge spillover is hugely important to innovation.) An open innovation model means labs do not have to worry about the things that slow the process down, such as intellectual property and cost-share. The timeframes for access to NSUF or other programs can still be a barrier, though, and GAIN is trying to make the whole system more efficient.

There are other steps DOE can take to improve overall efficiency. For instance, the range of requirements associated with contracting with DOE (e.g., audits) can kill startups. Speeding up the timeline for DOE contracting and collaboration (e.g., accelerating the contract review timeline, having a single point of contact) would also help, as would more streamlined budgeting (e.g., a fee menu listing items such as the costs for time in labs). In addition, better indexing and digitization of past DOE technical reports would be helpful low-hanging fruit; a lot of data has been collected in the past that people could use for designs going forward, but they will only be able to access that data if DOE scans and catalogues the reports. (Similarly, since the 1950s, the NRC has looked at many different advanced designs, and there is a need to get a lot of the documentation on what the NRC thinks about those designs on the NRC website to be easily retrievable.)

A key area where DOE could provide support is through its significantly under-utilized prize and challenge authority. As the government did for solar under SunShot, DOE could do a challenge for advanced reactors at a certain cost per watt. Nuclear innovation has to have a laser-like focus on getting costs – both capital costs and operating costs – down as much as possible. If advanced reactors are going to get deployed, they have to be competitive with American natural gas, cheap coal in Asia, and the incredibly low costs for utility-scale solar around the world. That has to be an explicit goal, or they will not succeed. That kind of goal could help create a new market for the next generation of nuclear, spurring private markets and entrepreneurial engagement. Some companies with highly modular designs are projecting installed costs (though not for a first-of-a-kind plant) of less than $2500/kW, which means those plants could compete with natural gas. If government support and targets could get advanced nuclear from $6000/kW to $2000-$3000/kW, private capital will start coming in more at that point.

CONGRESSIONAL POLITICS & ADVANCED NUCLEAR

New technologies and their capabilities, such as the dramatic improvements in waste and safety from Gen IV nuclear, can help break open old assumptions and start new conversations. A lot of policymakers – and some environmental advocates – tend to be more willing to listen to discussions about advanced nuclear than about existing technologies. Thanks to good, effective, persistent education and advocacy work by NGOs, there has been an enormous shift on advanced nuclear on Capitol Hill.

A lot of progress has been made over the past few years in getting Congressional staff up to speed on Gen IV, and big companies being positive and bullish on nuclear technology – emphasizing the technological advancements, jobs, and environmental benefits – will only further help Congress understand that advanced nuclear is within the realm of possibility. Bills have already moved through the House to open up the national labs. The principal cosponsors of one advanced nuclear bill are Sen. Inhofe, the leading climate denier in the Senate, and Sen. Whitehouse, the leading climate hawk. It is not possible to span a wider political divide than that. These are signs of progress. Things are changing rapidly, at least on the left, and the folks on the right are willing to play along. This bipartisanship is not happening in many areas, but it is in nuclear, and there is a need to take advantage of that.

Depending on the outcome of the 2016 elections, nuclear power's bipartisan support suggests it could move forward even in a divided landscape.

In the first two years of an Administration, new things become possible. There is going to be a need to press and make the case that nuclear will need a bunch of money – and soon. For instance, ITCs could be enacted to spur investment in advanced nuclear prototypes. One of the items that will be part of early discussions in a new Congress under a Clinton Administration will be the fate of Mission Innovation, the pledge made by countries in the lead-up to the Paris climate negotiations to double R&D on clean energy (broadly defined) over five years. The FY17 budget request was the first opportunity to reflect that in a budget, and that request mostly goes to energy efficiency and renewable energy, with maybe some work through ARPA-E. The request is not going far in the current budget process, in part because the Fossil Energy and Nuclear Energy Offices in DOE were not part of the budget increase request. A Clinton Administration will certainly honor the Mission Innovation commitment, but to get it through a Congress with at least one chamber controlled by Republicans, nuclear power could be key to a compromise. That being said, during a transition, the new Administration always scrambles to get a budget out (while putting a government together and everything else), and it might be better politically to have the idea start with Republicans in Congress rather than with the new Administration.

Not everything critical is in R&D. In the FY17 budget request, the Office of Nuclear Energy's R&D went down, but its overall budget went up to focus on accelerating deployment of SMRs (e.g., kicking off consent-based siting).

THE NUCLEAR ENERGY REGULATORY REGIME

Somewhat uniquely, the nuclear industry was born regulated, with a strong, independent, technically competent regulator put in place to ensure protection of public health, safety, and the environment. There are questions, though, about whether the Nuclear Regulatory Commission (NRC) is ready to review licenses from SMRs and non-light-water reactors if they become the next big thing.

NRC MANDATE & APPROACH

The NRC is focused on safety and security. That is its mandate. The NRC is aware of the challenging economics facing the industry, and it is making sure that licensees do not cut corners on safety. It has to be careful, though, to make sure its approach does not lean too far towards zero risk instead of adequate protection. The NRC also tends to be very deterministic, as its regulations are written that way, but it is trying to shift its culture to be more risk-informed, focusing the NRC's limited resources on risk-significant activities. The hope is that risk-informed regulation will allow the NRC to remove unnecessary burdens that may be hindering development and innovation. Reducing unnecessary burdens is more of a managerial and cultural challenge than something that requires new legislation.

The NRC has a clear role from the Atomic Energy Act. The NRC can only regulate with regard to what is necessary for adequate protection.

Arguments that the NRC should be more focused on climate change or on enabling innovation may be misdirected. The NRC has a clear role from the Atomic Energy Act. The NRC can only regulate with regard to what is necessary for adequate protection. Although the NRC is focused on safety, and climate change poses serious safety threats, the NRC's role does not encompass national energy policy. The NRC cannot reduce safety requirements or conduct less of a review because nuclear technologies may be good for climate change (or other environmental impacts). Promoting innovation is similarly outside NRC's focus, whereas the Department of Energy can be more promotional. Still, some are advocating for adding an arm to the NRC to work on innovation that could bringer safer technologies to market, and there is legislation under consideration to do that.

NRC LICENSING PROCESS

The NRC licensing process, which is complicated and highly prescriptive, is viewed as an impediment to private investment in and commercialization of advanced technologies. The current licensing process (Part 50 and Part 52) involves a major investment of time and money without interim steps that provide concrete feedback. From an investor point of view, the NRC is a dense black box, with no visibility into it and no outcome guarantees. As long as that continues, there will be reluctance from private investors.

The goal should be to have a licensing process that incorporates discrete stages, is more cost-effective and predictable for advanced reactors, and is more technology-inclusive. Having a well-defined, tightly controlled, more manageable process that is still stringent allows the market to attract private capital. Some startups feel that having a staged, milestones system similar to Canada's would be helpful and would provide greater clarity about regulatory timelines and costs. In fact, many startups are planning to license their technologies in Canada, where it is easier and faster to build than in the United States, although others feel that the NRC is the gold standard worldwide and so is the logical choice from a business perspective. The NRC has said that it views advanced reactors as an opportunity, and some startups are hoping that is true.

While more efficiency, speed, and effectiveness are certainly still possible in the NRC licensing process, there is progress occurring. For example, NRC staff are pursuing a multipart strategy to prepare for efficient and timely reviews of non-light-water technologies, including working closely with DOE and the industry to understand and prepare for advanced technologies. Some nuclear NGOs are also working to compile common key issues for various advanced technologies, identifying what is different and where the NRC needs to focus, so the NRC can respond more efficiently. The NRC is trying to listen and adjust, but it needs to know the priorities on which it should focus its limited resources.

The ability of the NRC to do speedier technical reviews for advanced designs is largely dependent on the quality of the application. In reviewing NuScale's SMR design, the NRC engaged with NuScale during pre-application and will complete design certification review in 2.5 years. Some designers also find a licensability review acceptable, where they bring the NRC a basic design and ask if there are any show-stoppers, though the range of uncertainty will depend on the level of detail in the design. Designers can also come in with portions of a design and get finality on that portion at the staff level. Canada does a similar kind of licensability review.

The issue with the speed of the NRC process may not always be as much about the NRC as about investor perceptions of the NRC. Investors hear too much from the advanced nuclear community about the issues with the regulatory process and think NRC licensing timelines are a bigger risk than they really are. The NRC's communications efforts should include greater efforts to communicate to investors and others the reality of what timelines look like.

One aspect of the NRC's efforts to improve speed, efficiency, and effectiveness for advanced reactors involves providing appropriate flexibility, recognizing the limitations of requirements that were meant for traditional light water reactors. For example, some advanced nuclear designs operate at ambient atmospheric pressures, which means they should not require the same level of containment systems, redundancy, backup cooling systems, and other legacies of light water design. How the NRC handles these differences has significant implications for how burdensome the licensing process is and how much advanced nuclear reactors will cost. DOE and the NRC are looking at the 1970s-era general design criteria meant for light water design to make sure they are not rotely applying criteria that are irrelevant to advanced designs. The NRC has already done this for sodium and high-temperature gas, and the regulatory guidance is out for public comment. Molten salt is still on the to-do list.

For the time being, the NRC is trying to be flexible through the use of exemptions. The NRC has to strike the balance between standards that apply uniformly and a willingness to look at technical information and jettison what is not applicable in a particular case; it is a mix of standard-setting and standard-forgiving. In the NRC's review of the NuScale SMR design, it provided exemptions where appropriate for inapplicable regulatory requirements. There is also a rulemaking underway to require smaller or no emergency planning zones for SMRs, as appropriate to the safety of the design. Rulemaking is expensive and time consuming for the NRC, though, so guidance and exemptions are the main route for now.

The NRC is also working on adjusting procedures to allow for more flexibility during construction. Nuclear developers using Part 50 have to go through multiple steps, with principal design criteria in one stage and a complete design later, which provides many opportunities for intervenors. Part 52, a reform after Three Mile Island, was intended for new reactors, which could get their design approved and then go build it, but those developers have to build exactly to the approved design. While there are risks and benefits to each approach, a lot of developers are still using part 50. The NRC is working on adjusting Part 52 to allow for easier design changes in the field during construction.

Efficiency and effectiveness could theoretically be further enhanced by some kind of coordinated licensing with other countries' nuclear regulatory authorities, given that the real market for advanced reactors is overseas. This coordination exists at a nascent level already, in terms of sharing information through the Multinational Design Evaluation Programme (MDEP), though there are bigger steps that could be taken in terms of harmonization. However, there will only ever be so much coordination. Each country's regulators view it as their non-delegable responsibility to ensure the safety of their citizens, and different regulators use different approaches to determine what is safe. A lot of countries still come to the United States to understand its approach, and several model their own nuclear power regulations after U.S. regulations.

ASPEN INSTITUTE FORUM ON THE FUTURE OF NUCLEAR ENERGY

August 9-12, 2016

The Aspen Meadows, 845 Meadows Road
Aspen, Colorado

Co-Chairs:
Phil Sharp & Steve Kuczynski

If the world is to meet the Paris goals of a near-zero carbon energy system by the second half of this century, every carbon-free option will need to be utilized. In the US, nuclear energy, which is currently 19% of generation, will likely need to be greatly expanded to meet this target, along with renewables, hydropower, carbon capture and storage, and demand reduction and efficiency. To commence and open the Forum, several potentially key questions emerge:

- What are the currently available and emerging advanced nuclear technologies, companies and related business models that offer the possibilities for a substantial expansion of global nuclear energy?
- How can the emerging, advanced reactor technology sector be enabled globally rapidly through private-public sector collaboration to be ready for deployment at scale by the 2030s, and what specifically is the US role?
- To ensure rapid global deployment of advanced reactors, what US and international policy frameworks are needed beyond R and D?
- As advanced technologies are rapidly developed, what portion of the current U.S. fleet of nuclear reactors can and should be maintained, and under what provisions?

The goal of this Forum is to move beyond a problem description and analysis of theoretical options. Instead, we hope to emerge with the sketch of a concrete action plan that can deliver safe and economic nuclear energy at the scale and pace needed globally. The sessions are structured to lay the groundwork for such a plan, and the last session will be devoted to creating it.

APPENDICES: AGENDA

TUESDAY, AUGUST 9

6:30 – 9:00 PM **Opening Reception and Dinner – The Meadows Restaurant**

WEDNESDAY, AUGUST 10

All sessions will take place in the Lauder Room of the Koch Building.

9:00 – 9:30 AM **Welcome and Introductions**
Introduction by David Monsma
Co-Chair Welcoming Remarks **Phil Sharp and Steve Kuczynski**

SESSION 1: Level-setting: Why Nuclear, How Much and How Fast?

This session is a general overview of imperatives of nuclear energy in the context of global economic development and climate change?

Moderator: Phil Sharp

Discussants:

The current state of nuclear energy and its impact on international security	**Dan Poneman**, President and CEO, Centrus Energy and Former Deputy Secretary of Energy
Global energy demand and the implications of the Paris accords	**Armond Cohen**, Executive Director, Clean Air Task Force
What does the U.S. need to do to meet its climate goals	**Sue Tierney,** Senior Advisor, Analysis Group
Where are we in the US? Business as usual – Three Nuclear Scenarios	**Lara Pierpoint**, Director, Office of Energy Supply Security, DOE

10:30 – 10:45 AM	**BREAK**	
10:45 – 12:00 PM	**SESSION I: (continued)**	
12:00 – 1:30 PM	**Lunch – The Meadows Restaurant**	
1:30 – 3:00 PM	**SESSION II: The Emerging Advanced Nuclear Technology Ecosystem and Business Models: Promise and Challenges**	
	Moderator: Steve Kuczynski	
	Discussants:	
	The Advanced Nuclear Technology Landscape and Business Model Implications	**Eric Ingersoll**, Co-Founder, Energy Options Network
	Innovation Among the Existing Players	**Jay Wileman**, President & CEO, GE Hitachi Nuclear Energy
	Advanced Technologies – Leapfrogging the Present	**Christina Back**, Vice President, Nuclear Technologies and Materials, General Atomics
	The Role of Start-ups and What They Need	**Leslie Dewan**, Co-Founder and CEO, TransAtomic
3:00 – 3:15 PM	**BREAK**	
3:15 – 4:30 PM	**SESSION II: (continued)**	
6:30 – 9:30 PM	**Reception and Dinner – The Monarch - 411 S Monarch St,**	
	Shuttles leave from the Aspen Meadows Reception Center starting at 6:15 PM. Walking from the Meadows takes about 20 minutes.	

THURSDAY, AUGUST 11

8:30 – 9:30 AM	**SESSION III: The Nuclear Energy Regulatory Regime**	
	Moderator: Phil Sharp	
	Challenges and Opportunities	**Stephen Burns,** Chairman, Nuclear Regulatory Commission
9:30 – 10:30 AM	**SESSION IV: Creating an Advanced Nuclear Innovation System**	
	Moderator: Steve Kuczynski	
	Discussants:	
	How does the tech sector innovate? Lessons for nuclear	**Ross Koningstein**, Engineering Director Emeritus, Google
	NRC Advanced Reactor Review Readiness	**Jennifer Uhle**, Director, Office of New Reactors, Nuclear

	Creating a pathway through the NRC for licensing	**Ashley Finan**, Project Director, Advanced Energy Systems, Clean Air Task Force
	The Government's Role in Nuclear Energy Innovation	**Jason Walsh,** Senior Policy Advisor, The White House
	Public/Private role in Advanced Nuclear Startups	**Matt Bennett,** Senior Vice President, Third Way

10:30 – 10:45 AM **BREAK**

10:45 – 12:00 PM **SESSION IV: (continued)**

12:00 – 1:30 PM **Lunch – The Meadows Restaurant**

1:30 – 3:00 PM **SESSION V: What to do about Existing Units?**

What issues are existing nuclear power plants having in the current market? What is the value of base load power in a competitive, carbon-constrained marketplace? What are the regulatory issues around extending existing plants to 60 or even 80 year licenses? Which of these issues are also important for future nuclear plants? How can we change the conversation to "nuclear and renewables" instead of nuclear vs. renewables? What policy proposals will enable this?

Moderator: Phil Sharp

Discussants:

Overview of Market and Regulatory Issues	**Bill Mohl**, President, Entergy Wholesale
State Markets and Regulations	**Ann McCabe**, Commissioner, Illinois Commerce Commission
Market and Pricing Issues – The Utility Perspective	**Joseph Dominguez**, Executive Vice President, Governmental and Regulatory Affairs and Public Policy, Exelon Corporation
Regulatory issues from the Utility's point of view	**Tamara Linde**, Executive Vice President and General Counsel, PSEG

3:00 – 3:15 PM **BREAK**

3:15 – 4:30 PM **SESSION V: (continued)**

No dinner is planned for this evening to allow participants to meet in small groups and/or explore Aspen – restaurant suggestions and reviews are available at: www.eataspen.com.

FRIDAY, AUGUST 12

8:30 – 10:00 AM	**SESSION VI: Closing Session and Recommendations** **Moderator: Josh Freed** **Discussants:** **Jan Mazurek**, Clean Power Director, Climate Works **Mark Peters**, Laboratory Director, Idaho National Lab **Ted Nordhaus**, Executive Director, Breakthrough Institute
10:00 – 10:15 AM	**BREAK**
10:15 – 11:00 AM	**SESSION VI: (continued)**

Forum Adjourns

PARTICIPANTS

Amir Afzali, Licensing Director- Next Generation Reactors, Southern Nuclear

Irfan Ali, Managing Director, Energy Innovation Reform Project

Christina Back, Vice President, Nuclear Technologies and Materials, General Atomics

Monica Beistline, Communications Chair, North American Young Generation in Nuclear; Online Work Week Manager, Exelon Corporation

Matt Bennett, Co-Founder and Senior Vice President, Third Way

Chrissy Borskey, Senior Director, GE Power

Bill Budinger, Founder, Former Chairman and Chief Executive Officer, Rodel, Inc.

Stephen Burns, Chairman, Nuclear Regulatory Commission

Armond Cohen, Executive Director, Clean Air Task Force

Ed Comer, Vice President, General Counsel and Corporate Secretary, Edison Electric Institute

Christian Deck, Director, Advanced Materials, General Atomics

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Alan Icenhour, Associate Laboratory Director, Nuclear Science and Engineering Directorate, Oak Ridge National Laboratory/UT-Battelle

Eric Ingersoll, Co-Founder, Energy Options Network

Barbara Judge, Chairman Emeritus, UK Atomic Energy Authority; Independent Non-Executive Director, Statoil

Ross Koningstein, Engineering Director Emeritus, Google

Ray Kopp, Senior Fellow, Resources for the Future

Maria Korsnick, Chief Operating Officer, Nuclear Energy Institute

Stephen Kuczynski, Chairman, President, and Chief Executive Officer, Southern Nuclear (*co-chair*)

Tamara Linde, Executive Vice President and General Counsel, PSEG
Thom Mason, Laboratory Director, Oak Ridge National Laboratory
Jan Mazurek, Director, Clean Power, ClimateWorks Foundation
Ann McCabe, Commissioner, Illinois Commerce Commission
Bill Mohl, President, Entergy Wholesale Commodities
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Kemal Pasamehmetoglu, Associate Lab Director, Idaho National Laboratory
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Lara Pierpoint, Director, Office of Energy Supply Security, US Department of Energy
Dan Poneman, President and Chief Executive Officer, Centrus Energy
Rachel Pritzker, President, Pritzker Innovation Fund
Phil Sharp, Former President, Resources for the Future (*co-chair*)
Susan Tierney, Senior Advisor, Analysis Group
Jennifer Uhle, Director of the Office of New Reactors, Nuclear Regulatory Commission
Jason Walsh, Senior Policy Advisor, The White House
Michael Webber, Deputy Director, Energy Institute, The University of Texas at Austin
Jay Wileman, President and Chief Executive Officer, GE Hitachi Nuclear Energy
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