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ADVANCED NUCLEAR TECHNOLOGY: PROTECTING U.S. LEADERSHIP AND EXPANDING OPPORTUNITIES FOR LICENSING NEW NUCLEAR ENERGY TECHNOLOGIES

HEARING

BEFORE THE

SUBCOMMITTEE ON CLEAN AIR AND NUCLEAR SAFETY

OF THE

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

JUNE 4, 2019

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ONE HUNDRED SIXTEENTH CONGRESS
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C O N T E N T S

ADVANCED NUCLEAR TECHNOLOGY: PROTECTING U.S. LEADERSHIP AND EXPANDING OPPORTUNITIES FOR LICENSING NEW NUCLEAR ENERGY TECHNOLOGIES

TUESDAY, JUNE 4, 2019

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
SUBCOMMITTEE ON CLEAN AIR AND NUCLEAR SAFETY,
Washington, DC.

The committee met, pursuant to notice, at 11:33 a.m. in room 406, Dirksen Senate Office Building, Hon. Mike Braun (Chairman of the Subcommittee) presiding.

Present: Senators Braun, Whitehouse, Capito, Ernst, Carper.

OPENING STATEMENT OF HON. MIKE BRAUN, U.S. SENATOR FROM THE STATE OF INDIANA

Senator BRAUN. Good morning. We are going to call this hearing to order. Thanks to everyone for being here today.

This hearing of the Clean Air and Nuclear Safety Subcommittee is called to order officially. The purpose of our meeting today is to examine the international and domestic outlook for advanced nuclear technologies. We look forward to using this information to help us inform the Nuclear Regulatory Commission's licensing and regulatory process for these new technologies. You will also help us consider the importance of maintaining American leadership in nuclear energy development and regulation.

I will begin by recognizing myself for a brief opening statement before turning the floor over to Ranking Member Whitehouse for 5 minutes. The last 70 years, the U.S. has been the global leader in civilian uses of nuclear technology. This leadership has offered great opportunities to our Country. A clean, reliable source of baseload electrical power, a strong domestic supply chain, able to develop and supply the world's largest and most powerful nuclear navy, ownership of the world's best nuclear technology, allowing the United States to lead the world in setting international nonproliferation standards, and the knowledge and experience needed to create a nuclear regulatory regime and a Nuclear Regulatory Commission.

The NRC's leadership not only assures nuclear energy is safe and secure, but is recognized around the world as the gold standard of nuclear regulation. But today, America's nuclear leadership is at risk. China and Russia are using nuclear energy to advance their

geostrategic interests. In turn, our domestic civilian industry is losing its competitive edge.

While the U.S. struggles to complete the first two new nuclear reactors in a generation, China has set a national target to build 58 gigawatts of nuclear power capacity by 2020, bringing four new reactors online just last year.

While nuclear charges ahead in countries like Russia, and China, in the U.S., our industry risks being caught in a downward spiral. America's supply chain, nuclear scientists, engineers, and regulatory standards, may be overtaken by our international competition. It is alarming. A recently released Atlantic Council report identifies the threats and consequences if the U.S. is no longer the nuclear energy leader. Senator Crap and our ranking member, Senator Whitehouse, were the honorary co-chairmen of the report.

The report states the growing dominance of Russia and China in current nuclear construction and export, with Russia's far greater international presence and China's growing ambition, is an immediate concern from a geopolitical standpoint as well as a safety and security perspective. Congress has already taken action to ensure that the Nuclear Regulatory Commission has the tools it needs to facilitate the development of this new reactor technology .

But what else can we do? Today, this subcommittee will examine the international and domestic outlook of advanced nuclear technologies to help inform the NRC's licensing and regulatory processes. The witnesses before us today will provide an important opportunity to consider the future of U.S. leadership in nuclear energy development and regulation.

I in particular am interested in hearing which technologies other countries are trying and how their regulatory environments may facilitate the development of advanced nuclear technology abroad. We may learn from their experiences and benefit by facilitating such development on U.S. soil. Additionally, I look forward to hearing how we can enable American nuclear innovators to export our own home-grown technology abroad.

Today's hearing is of the utmost importance. Without new reactors coming online, aided by the development of advanced reactors, the entire U.S. nuclear fleet could be idled within 20 years. Instead, with the right investments in these new technologies, and the regulatory apparatus to keep Americans safe, advanced nuclear could help power the American economy for the next 70 years.

Now, I would like to recognize Ranking Member Senator Whitehouse for his opening statement.

OPENING STATEMENT OF HON. SHELDON WHITEHOUSE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator WHITEHOUSE. Thank you, Chairman. I appreciate that we are having this hearing, and I am grateful to the terrific witnesses that we have here.

We are clearly witnessing a transition in the United States toward clean energy, despite some what I consider to be reprehensible behavior by the fossil fuel industry to interfere with that. Renewables and advanced nuclear technologies are leading this transition.

Renewables now provide nearly 19 percent of our energy, and the trajectory of their growth is steeply upward. Renewable energy capacity in the U.S. has more than tripled since 2008. In 2019, renewables will lead new additions to our energy grid.

Energy storage is a big part of the renewable story. The Federal Energy Regulatory Commission recently finalized its rule for battery storage on the electric grid. FERC's storage rule is projected to spur 50,000 megawatts of additional energy storage across the U.S. To its credit, FERC, led by Chairman Chatterjee, has rebuffed efforts to weaken the rule, setting a good precedent for the pending distributed generation rule.

Advanced nuclear technologies are the topic of today's hearing. The next-gen nuclear reactors can do two key things. One, help us reduce emissions as we move toward a clean energy economy; and two, potentially transform our existing nuclear waste stockpiles from liabilities into assets. I would like to offer, Mr. Chairman, for the record, an op-ed with our colleague, Senator Crapo, that he and I wrote entitled The U.S. Must Reassert Global Leadership in Nuclear Energy or lose out to Russia and China.

Senator BRAUN. Without objection, so ordered.

[The referenced information follows:]

Meteorologist says there's 'no doubt' climate change impacts tornadoes

thehill.com/hilltv/rising/446353-meteorologist-says-theres-no-doubt-climate-change-impacts-tornadoes

Tess Bonn

May 30, 2019

Meteorologist and storm chaser Quincy Vagell said Friday that there's "no doubt" that climate change can impact tornado activity.

"There's no doubt climate change can impact tornado activity," Vagell told Hill.TV co-hosts Buck Sexton and Don Calloway on "Rising."

"But it's hard to say that climate change by itself is going to cause of these tornado outbreaks," he added.

Vagell said research on the link between climate change and tornado activity is mixed.

While tornados dropped to record lows from about 2014 to 2018, he noted that rising ocean temperatures could be shifting tornadoes from the south-central part of the United States known as "tornado alley" towards the east.

"If you look in the bigger scale of things, I do think that when ocean temperatures are rising, you have more fuel in the Gulf of Mexico," he told Hill.TV. "What we're seeing is tornado alley is possibly being shifted a little bit from the plains eastward toward the Mississippi Valley, the Midwest and Southeast."

Vagell also said that researchers still have a long way to go on tornado predictions, saying meteorologists can only predict specific activity, such as where a tornado will touch down, a few days in advance, which gives little time for preparation.

"You can see the writing on the wall about two or three weeks in advance that we were seeing early, active pattern," he said. "But the tricky thing is you can't say exactly what city might get hit, you can just say, 'OK, Central United States should be bracing over the next couple of weeks.'"

Tornado season, which generally stretches from late spring to early summer, is in full swing.

According to the Washington Post, at least 225 tornados spanning multiple states have been confirmed over the span of just two weeks.

President Trump even declared a state of emergency in Kansas late Tuesday following a massive tornado in the area, and disaster aid has been made available to supplement the state's response efforts.

No fatalities have been reported. But, according to the Kansas City Star, 12 people have suffered storm-related injuries. Some people in other states, meanwhile, weren't so lucky.

A tornado turned deadly in Ohio over Memorial Day weekend, injuring more than 100 people and killing one.

—*Tess Bonn*

ago

Senator WHITEHOUSE. Thank you, sir.

Nuclear plants close because they get no compensation for being emissions-free. That is a big step backward for emission reductions, for climate change, and for the nuclear power industry. That is one reason why it is so important to factor the cost of carbon emissions into the energy market. That way, the compensation is built right in.

Our op-ed also discussed the partnership we have with Chairman Barrasso and Ranking Member Carper to pass two recent bills: the Nuclear Energy Innovation Capabilities Act, which will foster and accelerate development of advanced reactors through collaboration among our national labs, private industry, and academic institutions; and the Nuclear Energy Innovation and Modernization Act, which requires the Nuclear Regulatory Commission to develop a regulatory framework for licensing these new advanced reactor concepts.

These bills give a glimmer of hope that Republicans and Democrats can work together effectively on clean energy issues in bipartisan, legislative fashion. Sadly, however, I don't see a whole lot of regulatory bipartisanship in the NRC's new rule for U.S. nuclear power plants to prepare for or deal with the effects of climate change and sea level rise. With neither warning nor evidentiary support, Republican NRC members made this rule voluntary. Senator Carper and I are trying to understand why Republican commissioners would weaken the rule, when no public comments requested it, and NRC career staff advised against it.

The Fourth National Climate Assessment found that extreme rain events and more intense hurricanes are likely to occur over the next century, making the recent flooding events in Nebraska, Maryland, and Texas more normal. Now is the time to harden our nuclear facilities to deal with rising seas and more intense storms due to climate change, not to weaken them.

I still intend to understand why this happened, to make sure that nothing ex parte took place, and to keep pressure on the NRC to ensure that safety remains at the forefront of its decision-making. I hope that all my colleagues will join me and the Ranking Member in this oversight.

The Nuclear Regulatory Commission is known internationally as the gold standard of safety, and it should stay that way. Where our often-divided committee can find a way to set an example of bipartisanship, the NRC has no business injecting its own regulatory partisanship into the same question.

I look forward to hearing from our witnesses, and Mr. Chairman, I thank you.

Senator BRAUN. Thank you, Senator.

I am pleased that we have a great panel here today. We met you before the hearing started. Our witnesses bring decades of experience in the development, execution, and regulation of not only light water reactors, but also the next generation of advanced reactors. Our first witness, William Magwood, is the Director General of the Nuclear Energy Agency at the Organization for Economic Co-operation and Development. He has served in this position since 2014, and brings to this committee extensive experience in both the regulatory and developmental aspects of nuclear energy.

Prior to his service to the OECD, Mr. Magwood served as one of the five commissioners on the U.S. Nuclear Regulatory Commission. Mr. Magwood has also served at the U.S. Department of Energy, where he was Director of Nuclear Energy. During his tenure, he launched several important initiatives, including the U.S. Nuclear Power 2010 Program, and the Generation IV International Forum. Mr. Magwood holds bachelor's degrees in Physics and English from Carnegie Mellon University, and a Master of fine arts from the University of Pittsburgh.

Our next witness is Chris Levesque. Mr. Levesque is the President and CEO of TerraPower, an innovative American company working to bring advanced nuclear technologies to market. He brings over 25 years of experience in the nuclear industry, including senior leadership roles for two large new-build reactor projects in Finland and South Carolina. I learned about that latter last week. Prior to joining TerraPower, Mr. Levesque served as a vice president at Westinghouse Electric Company, where he directed a project for one of America's first new reactor construction efforts in several decades.

Mr. Levesque began his career as a nuclear submarine officer. He qualified as a chief engineering on the U.S.S. Boise. He holds a Bachelor of Science in mechanical engineering from Rensselaer Polytechnic Institute, and a Master of Science in mechanical engineering and Naval Engineer degree from MIT.

Our last witness today is Bob Perciasepe, the President of the Center for Climate and Energy Solutions. Prior to his current role, Mr. Perciasepe was Deputy Administrator at the Environmental Protection Agency, where he served as a respected expert on environmental stewardship, natural resource management and public policy.

In 2002, he joined the National Audubon Society, one of the Nation's oldest conservation organizations, as its Senior VP for Public Policy. He served as the group's chief operating officer from 2004 to 2009, where he worked to protect wetlands and expand environmental education, especially in urban areas.

He has also held top positions in State and municipal government, as Secretary of the Environment for the State of Maryland from 1990 to 1993, and as a senior planning official for the city of Baltimore, where he managed the city's capital budget. Mr. Perciasepe holds a master's degree in Planning and Public Administration from Syracuse University, and a Bachelor of Science degree in Natural Resources from Cornell University.

I want to remind the witnesses that your full written testimony will be made part of the official hearing record. Please keep your statements to 5 minutes, so that we may have time for questions.

I look forward to hearing your testimony, beginning with Mr. Magwood. Mr. Magwood, please proceed.

STATEMENT OF HON. WILLIAM D. MAGWOOD, DIRECTOR-GENERAL, ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT NUCLEAR ENERGY AGENCY

Mr. MAGWOOD. Thank you, Chairman, and good morning. Good morning to you and to Ranking Member Whitehouse and members of the subcommittee.

I am Bill Magwood, I am Director-General of the Nuclear Energy Agency, and I thank you for the opportunity to provide my perspectives on the future outlook for nuclear energy. As you noted, I have a written statement that I ask be included in the hearing record.

The Nuclear Energy Agency is an intergovernmental agency operating within the framework of the OECD, the Organization for Economic Co-operation and Development. As you may know, the United States help found the OECD as part of the Marshall Plan to help prevent wars and give countries a common purpose to improve their citizens' living standards.

The NEA has 33 member countries. Those countries are those with the deepest experience in nuclear technology, policy, and regulation. Our purpose for more than 60 years has been to facilitate cooperation among our members to address challenging issues associated with the use of civilian nuclear technology.

The United States is our largest member country, and each year dozens of Americans lead and participate in the many cooperative activities, including research projects and working parties underway within the context of the NEA. As the first American to lead the NEA since 1980, it is my particular pleasure to share observations based on the work of our agency, its expert staff, and the contributions of our members.

I will note that as I engage member countries around the world, I find that essentially every country with which we work, there is a very large level of uncertainty regarding the future of energy. This is particularly true in the case of nuclear. Existing plants around the world are faced with premature closure and few new plants are being built.

We have analyzed the reasons for these trends, and they are very, very complex. In OECD countries, first and foremost, I think the electricity markets have become dysfunctional in many areas. It is not unusual to see market prices for electricity zero or even negative during parts of the day.

We believe electricity markets require significant reform. Whatever goals countries have for the future, today's markets are not serving those objectives. For those who are concerned about emissions of carbon, the trends are particularly alarming. In the face of heavy investments in renewable energy sources, emissions are rising steeply, and last year, reached an all-time high.

You would think that this would provide an opportunity for nuclear. But the nuclear industry in many OECD countries has damaged reputations as a reliable supplier of plant and equipment. Cost overruns, schedule completion misses by decades, failed projects and very, very high cost estimates for new builds do not build confidence.

The fact is that the capacity to build nuclear power plants in countries that led to development in past decades has deteriorated. Skilled project leadership, supply chains for critical nuclear quality components and trained work force needed for effective construction simply have not been available to support projects in many OECD countries.

After not building nuclear plants for decades, they are like the overweight man who never exercises but decides to clear his driveway of snow in a Washington winter. Not a pretty sight.

Many government and industry leaders hope to leapfrog these difficulties by shifting from light water-based Generation III designs to small, modular reactors and Gen IV technologies that seek to shift old paradigms. About 30 companies around the world are vying to develop game-changing technologies, most of them working on Gen IV concepts. While there is great hope and enthusiasm in each of these companies, it is important to note that the developing of new light water technology, and shepherding it through regulatory approval, cost at least a billion and a half. Generation IV technologies will cost substantially more. And this is before billions are spent on demonstration facilities.

A typical company working to develop an innovative nuclear technology today has perhaps a dozen engineers and scientists devoted to the technology efforts and access to tens of millions of dollars. In comparison, I recently visited the Shanghai Institute of Applied Physics, which is developed a molten salt reactor technology. Molten salt reactors are a Gen IV technology that is high interest to several private sector companies. Because it represents a path of extraordinarily safe and efficient nuclear reactors, they have the potential to consume waste rather than generate it. The project in China has currently over 400 scientists and engineers hard at work developing this technology, with plans to build a demonstration reactor in the next decade.

Finally, with regard to nuclear regulation, we are not particularly concerned about the availability of regulators, given sufficient time to react to new technologies. I believe that the bigger challenge will be to find ways to avoid forcing companies to resolve technical and regulatory questions about nuclear technologies multiple times as they seek to introduce their technologies in multiple countries. For light water technologies, it takes about 4 years and nearly half a billion dollars to navigate approval processes. It is extraordinarily costly and inefficient if this is done in each country for each technology.

Moreover, if regulators can reach common positions on key aspects of technology, such as requirements for autonomous operation and the nature of emerging preparedness requirements, companies can deploy their technologies around the world, applying the same rules. For small reactors in particular, which these would benefit from access to large markets, this is a vital issue. We at the NEA are working with many member countries to explore how this issue might be resolved.

With that, Mr. Chairman, I will conclude my comments and be happy to answer any questions.

[The prepared statement of Mr. Magwood follows:]

Statement of
William D. Magwood, IV, Director-General of the OECD Nuclear Energy Agency
Before
The Senate Environment and Public Works
Subcommittee on Clean Air and Nuclear Safety

June 4, 2019

Good morning Chairman Braun and members of the Subcommittee. I am Bill Magwood, Director-General of the Nuclear Energy Agency. Thank you for the opportunity to appear before you today to provide my perspectives on the future outlook for nuclear energy.

The Nuclear Energy Agency is an intergovernmental agency operating within the framework of the Organization for Economic Cooperation and Development, the OECD. As you may know, the United States helped found the OECD as part of the Marshall Plan to prevent future wars, giving countries a common purpose to improve their citizens' living standards. The OECD—which is seen as an American success story—creates opportunities for U.S. businesses and workers throughout the world, and helps U.S. policymakers compare, evaluate, and understand the best options for both domestic and international policies.

Today's OECD helps save billions of dollars for American taxpayers and boosts the economic outlook for American businesses and workers. The U.S. has benefited from OECD work to combat international tax evasion, and currently the OECD is assisting the U.S. and other countries in developing a common approach to taxing the digital economy. The OECD is also helping to make the U.S. Foreign Corrupt Practices Act the gold standard around the world through the OECD Anti-Bribery Convention (see more about the OECD's activities in Appendix A).

The 33 members of the NEA are those countries with the deepest experience in nuclear technology, policy, and regulation. Our purpose for more than 60 years has been to facilitate cooperation among our members to address challenging issues associated with the use of civilian nuclear technology. We bring together the world's best expertise to establish common understandings about technical and policy matters and to find solutions in areas such as nuclear safety, radiological protection, nuclear waste, nuclear technology and economics, nuclear science, and nuclear law.

The United States is our largest member country and each year, dozens of Americans lead and participate in the many cooperative meetings, research projects, and working parties underway within the context of the NEA. We work very closely with senior officials and experts from the Nuclear Regulatory Commission, the Environmental Protection Agency, the Department of Energy, and the Department of State, as well as many U.S. experts from industry, academia, and national laboratories.

As the first American to lead the NEA since the 1980s, it is my pleasure to share observations based on the work of the Agency, it's expert staff, and the invaluable contributions of our members.

As I engage with leaders around the world, I find that in essentially every country with which we work, the level of uncertainty regarding the future of energy is currently at a very high level—perhaps the highest it has been since the oil shocks of the 1970s. In some ways, the uncertainty is even higher than that tumultuous period because we are today faced with radical shifts in technology, policy, and politics that make the picture of the future murky and unreliable.

This is particularly true in the case of nuclear energy. Just as many countries around the world seek to reduce emissions into the environment, nuclear energy in the developed countries of the OECD—including the United States—is on a declining path. Existing plants are faced with premature closure and few new plants are being built.

We have analyzed the reasons for these trends and they are varied and complex. Some countries have made political decisions to eschew nuclear or to emphasize other energy options at the expense of nuclear energy. Some countries face public resistance and concern about nuclear power plants in the aftermath of the Fukushima Daiichi accident. But the most important drivers for the declining prospects for nuclear energy in the U.S. and in many other OECD countries are economic.

First and foremost, the electricity markets have become dysfunctional in many markets around the world. It is not unusual to see market prices for electricity at zero or even negative during parts of the day. In many countries, the power companies that have provided reliable supplies of electricity face shrinking revenues just as the need for new investment is at its highest. I have had the leaders of power companies in several countries indicate to me that the only capacity they can afford to build is that which is subsidized by governments. These are no longer "markets" in any real sense.

Governmental interventions—including out-of-market subsidies and required shares for variable renewable energy—have contributed to these developments. However these conditions developed, they make the economics of operating a nuclear power plant very challenging. With zero marginal cost, variable renewables remove the floor in market prices, requiring baseload plants to either idle or operate at a loss during critical periods. Add historically low prices for natural gas in many places and the top of the market is compressed as well. As a result, nuclear plants are closing.

Overall, we believe that the electricity markets require significant reform. Around the world, whatever goals countries have for the future, today's markets are not serving their objectives. Markets should be balanced to provide for year-round reliability and stability and to enable electricity suppliers to make the investments needed to meet society's energy security and environmental goals. For those who are concerned about the emissions of carbon, the trends are particularly alarming. In the face of heavy investment in renewable energy sources, emissions are rising steeply and reached an all-time high last year.

We all certainly recognize the important and growing role of variable renewable energy in the world's long-term energy mix, and expect that wind, solar, geothermal, and other technologies will be essential in the transformation of the electricity sector over the next few decades. But the results thus far highlight the need for strategies that more accurately reflect the costs and attributes of renewables.

A report released by the NEA in January entitled "The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables"[1] demonstrates the vital role that variable renewables can play in the

[1] See the full report at https://www.oecd-nea.org/ndd/pubs/2019/7299-system-costs.pdf

future energy supply—but as part of a well-balanced portfolio (see additional information in Appendix B). In the case of very high shares of variable renewables, such as 75%, our work shows that the cost of providing electricity skyrockets—easily double what it could be because of the variable and unpredictable nature of renewable supply and the fact that, according to our work, total capacity would need to triple in size if the share of renewables were to reach very high levels. Such a system would also be faced with considerable inefficiencies and many technical challenges.

The contribution of renewables should reflect the realities of the electricity system in which they are to be deployed and the cost of the renewable resources available. Each country should assess the full costs of all its potential sources of supply and develop the balance of renewable and baseload supplies that best fits its particular circumstances. The balance is likely to be different from country to country. As it becomes clear that the amount of baseload supply needed in the future is not zero, each country will need to decide how it will meet its future electricity supply needs.

This would certainly appear to create an important opportunity for nuclear energy. Nuclear energy is the only expandable, dispatchable source of large-scale electricity that does not generate air emissions. Countries around the world have benefitted from the reliability and price stability provided by nuclear power plants for more than fifty years. Yet, nuclear energy is on path to decline in North America, Europe, and OECD Asia.

Today, few plants are under construction in OECD countries. As reflected by the projects underway in the United States, France, Finland, and Slovakia, the nuclear industry in most OECD countries has a damaged reputation as a reliable supplier of plant and equipment. Eye-watering cost overruns, schedules for completion missed by a decade, failed projects, and stratospheric cost estimates for new builds do not build confidence.

The fact is that the capacity to build nuclear power plants in the countries that led nuclear development in decades past has deteriorated. The skilled project leadership, supply chains for critical nuclear-quality components, and trained workforce needed for the effective construction of new nuclear plants simply have not been available to support nuclear projects in most OECD countries. After not building nuclear plants for decades, they are like the overweight man who never exercises but decides to clear his driveway of two feet of snow in a Washington winter. It's not a pretty sight.

Among OECD countries, only Korea has maintained a long-term building program that enables it to supply nuclear plants to cost and schedule requirements. In contrast, Russia and China are quite proficient in building plants and are currently the most aggressive countries in the international market for new plants. Both countries have benefitted from continuous build programs and have developed world-class construction expertise and robust supply chains. Organizations from these countries are winning contracts in both developing countries and in highly developed countries. Russia has proven its capabilities in Iran and Bangladesh and is now developing projects in Finland, Turkey and other countries. China has signed agreements to build in Argentina and is likely to construct a plant in the United Kingdom. In addition to their construction capabilities, both countries are offering financing for projects that can make the difference between an aspiration to build and a project to build.

The success of suppliers from Russia, China, and Korea demonstrates that the difficulties faced by projects in the US, France, Finland and elsewhere have less to do with the nature of nuclear projects and much more to do with the lack of proficient, experienced construction capacities in countries that haven't hosted continuous nuclear build programs since the 1980s.

Given the experiences of recent years, I don't believe you will find any CEOs of U.S. electric utilities who would consider building a nuclear plant today. The costs are too high, the risks are too high, and the uncertainties are too high. Some CEOs have told me that they believe we have seen the last large light water reactor to be built in the United States.

Many government and industry leaders hope to leap-frog these difficulties by shifting from light water-based Generation III nuclear designs to new technologies—small modular reactors that can be largely built in factories and Generation IV technologies that seek to shift old paradigms. Just last week, at the Clean Energy Ministerial held in Vancouver, governments and industry came together to discuss and pave the way for these new technologies. Most of the nuclear discussions were held in the context of the Nuclear Innovation: Clean Energy Future initiative—NICE Future—which was launched last year by the U.S., Canada, and Japan.

Gas-cooled reactors, liquid metal reactors, molten salt systems and others are being pursued. These are exciting technologies that offer many bright hopes. If successful, the potential exists for the introduction of technologies that have economic, flexibility, and safety characteristics that could entirely change the global discussion about energy.

Beyond even the shift in technology, discussions in Vancouver highlighted a shift in leadership in nuclear technology development from the government sector to the private sector. It is estimated that more than 30 companies are today developing advanced nuclear energy technologies—most of them Generation IV technologies. Many others are working on fusion energy as well.

This new, private sector-led approach to development is somewhat inspired by the success by NASA in encouraging innovation in space technology by supporting the private sector. Governments, particularly the U.S., Canada, United Kingdom, and Japan are emphasizing this approach and have moved away from the traditional government-led development model that led to past nuclear technology innovations.

This new approach, however, faces important questions. As we watch this transition from government to private sector leadership, I highlight three primary areas of concern that must be addressed if these initiatives are to be successful.

First, it is important to recognize the unique nature of nuclear technology development. The reason nuclear technology development has been led in the past by governmental organizations is because it is very technically challenging, expensive work that requires access to facilities that can manage safety and securely nuclear materials. As anticipated by DOE's Gateway for Accelerated Innovation in Nuclear (GAIN), national laboratories can support some of these needs.

This requires an approach to enable companies to benefit from the broad expertise and capabilities in national laboratories. This matter was discussed last week in a unique meeting sponsored by the Canadian government that brought together a dozen or so leaders from companies developing new nuclear technologies for market and the Generation IV International Forum (GIF). The GIF, which is facilitated by the NEA, has been active for nearly 20 years as a global framework for advanced reactor research cooperation between the world's leading countries in advanced research. It is led by government and national laboratory experts who have always worked in long-term government-sponsored research and development activities. The meeting demonstrated that the needs of the private sector are driven by investor impatience and the need to support regulatory processes. These imperatives contrasted with the long-term research approach of the government sector.

These discussions also highlighted that developing a new light water technology and shepherding it through regulatory approve is likely to cost at least $1.5 billion. Generation IV technologies are likely to cost substantially more. The typical company participating in the Vancouver meetings have perhaps a dozen engineers and scientists devoted to their technology development efforts and access to a few tens of millions.

In comparison, I recently visited the Shanghai Institute of Applied Physics, which is developing a molten salt reactor technology. Molten salt reactors are an area of high interest to several private sector companies—including TerraPower which is represented here today—because it represents both a path to extraordinarily safe and efficient nuclear reactors that consume nuclear waste rather than generate it. The project at SINAP currently has over 400 scientists and engineers hard at work developing the technology with plans to build a demonstration reactor within the next decade. In terms of resources, this project is larger than the combined resources of all the companies that participated in the Vancouver meetings.

I make this contrast to highlight that the private companies upon which OECD countries are largely relying will need access to orders of magnitude more resources to be successful. Investors will look for early indications of success and a clear opportunity to enter the market in the foreseeable future. How some of the 30-odd companies aspiring to bring Generation IV technologies to reality will acquire the resources and expertise necessary for success is not clear. Government-sponsored technology projects in China and Russia appear to have a clearer path to market.

The second challenge is related to an issue I mentioned earlier—the dysfunction in today's energy markets. Prices for electricity in the U.S. are very low, which is good for consumers, but it provides limited incentive to private investors to support new nuclear energy technologies. There are, fortunately, visionary investors who are willing—for the sake of future generations—to launch the exploration of new technologies. But billions will be needed. In contrast to NASA, which provided the market to incentivize private space efforts, the markets for energy today cannot sustain fully depreciated existing nuclear power plants. It is, therefore, challenging to make an economic case for massive private investment in unproven technologies.

A possible exception might be the case of "microreactors", which could be deployed for specific niche purposes—such as providing energy for remote communities, to support military deployments, or mining operations—but these face interesting regulatory questions regarding their deployment that remain to be resolved.

And this brings me to the last major challenge: regulation.

I will begin by stating that I am not particularly concerned about the ability of regulators, given sufficient lead time, to react to new technologies. Many observers call for more "streamlined" licensing to ease the introduction of advanced technologies, but I believe that the current frameworks in the U.S. and most other nuclear safety regulatory agencies can be adapted to license new technologies.

Clearly, more can be done to make the process simpler, but I don't believe radical changes are necessary to move technologies forward. The NRC is considering how to modernize its framework and adapt it to non-light water reactor technologies, but even without these analyses, work conducted in the course of DOE's effort to develop the Next Generation Nuclear Plant a decade ago demonstrated that the existing regulatory tools available to the NRC would allow for the licensing of an advanced technology.

Rather than a matter of framework and regulation, the most significant challenge for regulators will be to adjust the mindset of their staffs toward new concepts and technologies. They must be more willing to

become partners in innovation, though without violating their independence as nuclear safety regulators. Each regulator will need to manage its way to the appropriate balance.

The private sector has also expressed interest in having the NRC develop a step-wise approach to licensing new technologies along the lines of the pre-licensing vendor design reviews (VDRs) that can be conducted by the Canadian Nuclear Safety Commission (CNSC). This type of approach is helpful to small companies looking for ways of communicating progress to potential investors.

Nevertheless, at the end of the day, there is no short-cut to licensing advanced nuclear reactor technologies; nor should there be. The process will be expensive, time-consuming, and likely require testing that can best be completed in established nuclear complexes such as national laboratories. No matter how regulators approach the licensing, the information they will need to make licensing decisions will be similar around the world.

This will require greater international coordination in the use and sharing of research facilities around the world. The NEA is today working with our members to address gaps in the global framework for the testing of new nuclear fuels and materials. This experience will be invaluable as regulators seek technical information regarding advanced reactor systems.

In my view, the bigger challenge for regulators will be to find ways to avoid forcing companies to resolve technical and regulatory questions about new technologies multiple times as they seek to introduce their technologies in multiple countries. Today, obtaining regulatory approval for a technology in Korea or France means very little if you wish to build the technology in the United States. For light water technologies, it requires about four years and the order of half a billion dollars to navigate approval processes. It is extraordinarily costly and inefficient if this must be done in each country for each technology.

Moreover, if regulators can reach common positions on key aspects of technologies—such as requirements for autonomous operation and the nature of emergency preparedness requirements—companies can provide their products around the world applying the same rules. For small reactors in particular, which would benefit most from access to the largest practical market, this is a vital issue. We at the NEA are exploring how this issue might be resolved.

Conclusion

The need for nuclear energy technology is clear, but the path in the U.S. and other OECD countries to develop and deploy these technologies is not. The only major Generation IV nuclear technology demonstration projects underway today are in China, Russia, and India. These countries have implemented and continue to implement advanced reactor demonstrations across a broad front. Russia's BN-800 sodium-cooled fast reactor and floating nuclear power plant and China's high temperature gas-cooled pebble-bed modular reactor are examples of successful projects and more are on the way.

The traditional nuclear development countries have not implemented a successful Generation IV reactor technology program since the 1980s and the expertise and infrastructure these countries built over the decades have eroded dramatically.

The U.S. and many other OECD countries rest their hopes on a large number of mostly small innovation companies that aspire to develop game-changing technologies for the future. But to be successful, these companies will need a supportive market, access to significant expertise and resources, and regulators who are prepared to support innovation and the development of a global market.

Appendix A: Additional Background on the OECD

The United States helped found the Organization for Economic Co-operation and Development (OECD) as a bulwark against further wars, giving countries a common purpose to improve their citizens' living standards and quality of life. Today, the OECD has updated its mission to help countries design and deliver "Better Policies for Better Lives". The OECD's work creates opportunities for U.S. businesses and workers throughout the world and helps U.S. policymakers compare, evaluate, and understand the best domestic policy options for their constituents. Today's OECD helps save billions of dollars for American taxpayers and boosts the economic outlook for American businesses and workers. Here are just a few of the ways the OECD makes a difference and adds value for the U.S.

THE OECD: REAL RESULTS FOR THE UNITED STATES

Levelling the Playing Field for U.S. Businesses, Saving Money for U.S. Taxpayers

- The OECD's Export Credit Agreement **saves American taxpayers over $800 million per year**. It prevents countries from distorting international markets through subsidized export credits or tied aid. This reduced costs and **allowed U.S. firms to increase their exports by billions annually**. Taxpayer savings result from guidelines on interest rates and risk premiums charged for export financing, and from rules on the use of donor aid.
- The U.S. has also benefited from OECD work to **combat international tax evasion and promote transparency**. Close to $85 billion has been collected through voluntary disclosure and similar initiatives in advance of the first exchanges under the OECD's Common Reporting Standard, which was endorsed by the G20 and more than 100 jurisdictions. **Almost $10 billion of this additional, unplanned revenue has been collected in the U.S. alone.** To enable countries to implement the Standard in a consistent and cost-effective way, the U.S. and other members asked the OECD to procure a Common Transmission System – the IT infrastructure to undertake the bilateral exchanges of tax information. The OECD has also provided a platform for tax cooperation, which is the best way to protect and enhance countries' sovereignties while providing more certainty to business. The OECD/G20 BEPS project has facilitated a revision of **transfer pricing guidelines** and the **model tax treaty** which underpin over 3700 bilateral arrangements. The U.S. has inspired these rules, which are now endorsed by all OECD and G20 countries.
- Commitments made by OECD members under the **OECD Codes of Liberalization of Capital Movements**, have resulted in opening their markets to U.S companies. In the process of adhering to the Codes, new European countries have extended to US companies the liberalization benefits of EU common markets in a range of industries, from financial services to films. Commitments under the Codes to refrain from using capital controls also contributed to discouraging exchange rate management aimed at gaining unfair trade advantages.
- More than $1 trillion in bribes are paid worldwide each year, which some experts estimate to be equivalent to a 20% tax on foreign investment by U.S. and other countries' firms. The OECD **is helping to make the U.S. Foreign Corrupt Practices Act the gold standard around the world through the OECD Anti-Bribery Convention**. U.S. peer pressure on other Parties through the Convention's monitoring process is paying off. For example, in a recent case the authorities in Brazil and Switzerland joined those in the U.S. to successfully prosecute a Brazilian company for foreign bribery, resulting in the largest global fine ever – USD 3.5 billion.
- Through the **OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas** the OECD is leveling the global playing field for U.S.

companies. The EU and others have followed the US example and recognized OECD guidance on due diligence in their laws and regulations.

- The services sector generates 80% of American jobs and 75% of U.S. economic output. The OECD Services Trade Restrictiveness Index (STRI) **helps the U.S. government and business community to identify trade barriers and regulatory obstacles in both the US itself, as well as in foreign markets** on a sector-by-sector basis.
- The OECD Guidelines for the Testing of Chemicals and Good Laboratory Practices **save member governments and industry approximately $165 million annually – a significant portion of which accrues to the U.S. government and chemical industry**.
- The OECD is also working to **eliminate unfair competition that can hurt U.S. companies abroad**. Working with governments around the world, the OECD is helping clarify the nature and role of state-owned enterprises and how they may shape trade. Likewise, the OECD Declaration on International Investment and Multinational Enterprises and the OECD Guidelines for MNEs provide certainty to investors as the most comprehensive set of recommendations on responsible business conduct in existence.
- As American firms compete in global value chains, OECD measurements on trade in value-added (TiVA) provides American policymakers with **evidence to make smarter choices on trade policy and the best new markets** for U.S. firms, both export destinations as well as sources for intermediate inputs.
- **The U.S. — the world's 4th largest steel producer — suffers significantly from global excess capacity.** The OECD facilitates the **Global Forum on Steel Excess Capacity in the context of the G20** to address industry reform. **The U.S. has been a founding member and key partner of the OECD Steel Committee** since 1978.

Supporting Stronger Domestic Policies for America's Future

- The OECD is a **go-to resource for American policymakers** and the public to identify information and strategies to build better policies. **The Congressional Research Service has cited OECD facts and figures in its reports to Congress more than 1,500 times since 2003**.
- The U.S. spends more than $600 billion on public K-12 education annually. The OECD's Program of International Student Assessment (PISA) **helps to measure return on education investment** – specifically, how American 15-year-olds perform in reading and math and science. The Program for the International Assessment of Adult Competencies (PIAAC) measures proficiency in numeracy, literacy and problem-solving in technology-rich environments.
- The U.S. spends nearly $20 billion each year to help put Americans back to work. The Job Creation and Local Economic Development report **identifies U.S. regions with the strongest job-creation prospects**. The Skills Strategy and the OECD's work on displaced workers suggest **cost-effective improvements to provide job training and opportunities for all**.
- Small businesses are the backbone of the U.S. economy, accounting for 99.7% of all employer firms and nearly half of private-sector employment. OECD data **help the U.S. do better by small businesses,** monitoring financing needs and gaps and exploring policy options to **get SMEs the funds they need.**
- The OECD has contributed to the debate on domestic **tax reform** (2016 U.S. Economic Survey, 2016 Revenue Statistics) with **proposals to address the high corporate tax rate**. The U.S. business

community has made a strong contribution to the 2016 OECD survey on the sources of tax uncertainty, which will help countries develop a tax system that promotes investment, trade and balanced growth.

- Knowledge-based capital (KBC) accounts for more than half of U.S. business investment. OECD research has **proven the benefits of innovation-driven business models**. Under U.S. leadership, we have adopted the OECD Principles for Internet Policy Making.
- U.S. health spending per capita is higher than that of other OECD members. The OECD compares detailed health spending data across countries and identifies ways **to do more and better with less.**

A Partner for the U.S.

The OECD is doing all this work with a **decreasing share of U.S. contributions**. Thanks to financial reforms, America's share of contributions to the OECD core budget has **fallen from 25% to 20.6%** in the last decade. According to the Department of State, the U.S. paid over $104 million in 2008 to the OECD via the Contributions to International Organizations account. In 2017, the contribution to the OECD was $70 million. The OECD work program and budget are managed through best standards, applying results-based management to provide U.S. tax payers with the **highest possible value for money**. Looking to the future, the share of **U.S. contribution to the core budget is expected to continue decreasing to 18.2%** within 10 years, potentially less if new countries join the organization.

Appendix B: The System Costs of Electricity

THE SYSTEM COSTS OF ELECTRICITY REFLECT THE TRUE COSTS OF DECARBONISATION

- Limiting the rise of global temperature to less than 2°C represents an enormous challenge for the whole electricity sector.
- Decarbonising the electricity sector in a cost-effective manner while maintaining security of supply requires the rapid deployment of *all* available low-carbon technologies.
- Today's electricity markets make investment in any unsubsidised low-carbon technology economically impractical.
- System costs are the result of inefficiencies imposed on the entire electricity system due to the increased share of variable generation.

What's the issue?

The future is electric. Decarbonising the energy sectors and the economies of OECD countries will require electrification of not just the transportation sector, but also industry and buildings. Effective action to reduce carbon emissions and to limit climate change depends on the creation of a robust low-carbon electricity sector.

Reducing the carbon intensity of the electric power sector to 50 gCO_2 per kWh (which would be necessary to meet Paris Agreement goals) is a major challenge. This level is one-eighth of the current levels and requires a rapid and radical transformation of the power system with the deployment of low-carbon emitting technologies such as nuclear, hydroelectricity and variable renewable energy (VRE). This will mean phasing out coal and strictly limiting the use of gas-fired power generation.

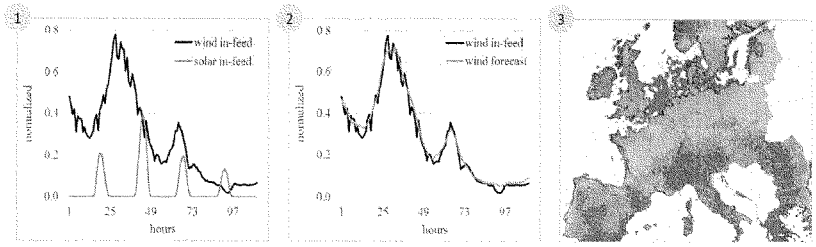
This change must be approached carefully and with a full understanding of costs and impacts of various technologies. For example, increasing the share of variable renewable energy (VRE) results in large inefficiencies in the entire electricity system.

These issues appear as overall system costs, caused mainly by the intrinsic characteristics of variable generation, are currently not correctly allocated to the generation sources that cause them. They also result in significant challenges for the management of the electric system, and volatile and unpredictable electricity prices.

In part because of these effects, the existing electricity market structures make investment in any unsubsidised low-carbon technology economically impractical.

Given the massive investments that the realisation of the decarbonisation transformation requires, it is of paramount importance to create long-term frameworks that provide stability and confidence for investors in all low carbon generation technologies. It is also imperative to realign electricity systems and electricity markets to ensure security of supply and system reliability in a cost effective manner.

System costs are mainly due to characteristics intrinsic to variable generation



VREs are not always available

VREs are difficult to predict

Good VRE sites are distant from load centres

What should policy makers do?

Radically decarbonising the electricity sector to 50 gCO_2/kWh in a cost-effective manner while maintaining high levels of security of supply therefore requires five complementary policy measures:

Recognise and fairly allocate the system costs to the technologies that cause them: Carbon pricing will recognise the environmental attributes of low-carbon generation, while capacity remuneration could recognise dispatchability. Exposure to electricity prices would internalise profile costs, and remunerate each unit of electricity generated at its true value for the system.

Foster truly competitive short-term markets for the cost-efficient dispatch of resources. Marginal cost pricing based on short-term variable costs is the appropriate mechanism to ensure the optimal utilisation of existing resources, i.e. to produce a MWh of electricity at the lowest possible costs at any given moment and to expose generators to the discipline of market prices.

Encourage new investment in all low-carbon technologies by providing stability for investors: In creating sustainable low-carbon electricity systems, all low-carbon technologies will need to play a part. However, their high capital intensity requires specific financing solutions as they will not be deployed solely on the basis of marginal cost pricing in competitive markets. This holds for all low-carbon technologies. This is why policy makers have to make tough calls on striking the appropriate balance between out-of-market support and exposure to wholesale market prices for low-carbon technologies with high fixed costs such as nuclear and VRE. Feed-in tariffs (FITs), long-term power purchase agreements (PPAs), contracts for difference (CFDs), regulated electricity tariffs, feed-in premiums (FIPs) or even direct capital subsidies through, for instance, loan guarantees, are all appropriate instruments to achieve long-term security of supply with low-carbon technologies.

Enable adequate levels of capacity and flexibility, as well as transmission and distribution infrastructure: generation is at the heart of any electricity system, but the electricity system requires frameworks for the provision of capacity, flexibility, system services and adequate physical infrastructures for transmission, distribution and interconnections. The variability of VREs and new technological developments make these complementary services increasingly important. It is also important to recognise the positive contribution to system stability and inertia of large centralised units such as nuclear power plants or hydroelectric dams and to value them appropriately.

Implement carbon pricing, as the most efficient approach for decarbonising the electricity supply: This approach would increase the cost of high-carbon generation technologies, reduce greenhouse gases and enhance the competitiveness of low-carbon technologies such as nuclear and VRE. Carbon pricing will produce an overall gain for society. However, it will also produce losses for some stakeholders, in particular, fossil fuel producers and their customers. Appropriate policies to facilitate a "fair transition" for the affected businesses and households, and particularly those in vulnerable regions and communities will be needed. No one can be left behind.

Why is this important?

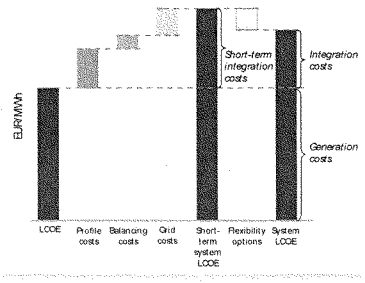
The ultimate objective of policy-making in this area is the decarbonisation of the electricity markets. Current projections are that this goal would require a 73% reduction in the world's total annual CO_2 emissions from electricity generation and an even more ambitious 85% reduction of the annual emissions in OECD countries. Ambitious decarbonisation targets require the optimum use of all available low-carbon technologies, but current electricity markets are not enabling the reduction in carbon intensity necessary to meet the Paris Agreement goals.

Projections in the new NEA study reveal that the true costs of decarbonisation are not being reflected in today's electricity markets. For example, increased share of variable renewable energy (VRE) results in large inefficiencies in the entire electricity system. One of these inefficiencies manifests as the vast excess capacity that is needed to meet the demand. For example, if a system were to go from 0% to 50% VRE penetration, installed capacity would need to double to meet the same demand.

At the same time system costs significantly increase. For example, under the same scenario (increase from 0% to 50% VRE penetration), system costs would make up 35% of total costs to meet the same demand.

Finally, existing electricity frameworks lack signals that encourage long-term planning and investment in low carbon technologies to ensure security of supply and system robustness.

Illustration of system costs



Source: OECD (2015), *Projected Costs of Generating Electricity: 2015 Edition*, IEA and NEA joint publication, OECD, Paris.

Who is working on this?

This study was prepared by the Nuclear Energy Agency, a specialised agency inside the Organisation for Economic Co-operation and Development family. For many years the NEA has analysed different aspects of the costs of electricity. This work focuses on all sources of power generation, examining the plant-level costs, system costs and security of supply. NEA's goal is to enable policy makers and the public to take better-informed decisions along the path towards fully sustainable electricity systems

Senate Committee on Environment and Public Works
Subcommittee on Clean Air and Nuclear Safety
Hearing entitled, *"Advanced Nuclear Technology: Protecting U.S. Leadership and Expanding Opportunities for Licensing New Nuclear Energy Technologies"*
June 4, 2019

Questions for the Record from Chairman Bararasso

1. **Establishing a common set of technical information for different national nuclear regulatory would help deploy advanced nuclear technologies. It could save time and money for nuclear companies seeking to license and deploy advanced nuclear technologies around the globe. Would an American-led, bilateral pilot program help test this concept prior to establishing a full multi-national initiative?**

Response from Director-General Magwood:

Achieving multi-national licencing is recognized widely as a very important goal around the world. The market for nuclear energy technologies is a global one and access to the largest practical market is particularly essential for small reactor designs. In contrast to traditional nuclear power plants, which benefit from the economy of scale inherit in larger generating capacities, small modular reactors (SMRs) are expected to achieve their most advantageous economy by being produced in large numbers (analogous to commercial airliners). Achieving larger production runs necessitates access to the global market.

Today, each national regulator requires independent licencing processes which may typically require approximately four years to complete. More challenging for new technologies, regulators may apply different industrial standards and establish different design and operating requirements which inhibit the ability to produce a single design for the entire market.

There have been successful bilateral efforts in the past in which regulators have reduced licencing times and costs through regulator-to-regulator cooperation. An example is the Sizewell B plant in the United Kingdom; cooperation between the U.S. Nuclear Regulatory Commission (NRC) and the U.K. Nuclear Installation Inspectorate enabled the U.K. regulator to apply NRC analyses in its assessment of the Westinghouse-designed plant (which was similar to plants already operating in the U.S.). Today, similar cooperation is advancing between U.S. and Canadian regulators with the aim to accelerate Canadian reviews.

While bilateral activities such as these have clear benefits, they are one-off efforts that do not establish clear mechanisms that can be readily applying to broader multilateral efforts. Further, as can be seen in the case of the former cooperation related to Sizewell B, bilateral approaches do not necessarily provide a clear approach for the bilateral partners to easily replicate their cooperation in the future.

At the same time, I am not confident that we will ever see "global licencing" of nuclear technologies. The public in all nations have the right to expect that the nuclear safety regulators in their countries have completed the assessments necessary to assure the safety of nuclear technologies deployed in their countries. Regulators take this responsibility very seriously.

The Nuclear Energy Agency, working closely with the U.S. and other governments is discussing an approach that could allow a limited number of like-minded regulators to engage in coordinated licencing of new technologies. If successful, this initiative could open a multi-national market to new technologies and provide a ready approach to speed licencing in additional countries that agree to adopt the outcomes of the coordinated licencing effort.

I believe an approach such as we are currently exploring is the best approach to opening the widest possible market to new technologies.

2. **Based on your experience as a member of the Nuclear Regulatory Commission, how does American leadership on nuclear regulatory issues affect global safety and security standards and practices?**

Response from Director-General Magwood:

For decades, the Nuclear Regulatory Commission was often cited as the "gold standard" of nuclear regulators and many countries sought to adopt U.S. approaches to their own practices. The excellence of the NRC remains unquestioned around the world, and NRC assessments of technical issues are highly regarded.

Nevertheless, the public and political reaction in many countries to the Fukushima Daiichi accident in Japan has led to a wave of conservatism in some countries that is divergent from the approaches maintained by the NRC. The NRC's framework relies on quantified assessments of the safety benefits of potential regulatory actions and are predicated on the ability of plant operators to respond appropriately to a range of operating and accident conditions. This contrasts with the policy-driven approaches to regulatory decision-making that have developed in many countries in recent years.

An example of this divergence is the challenging conditions operators in many countries must meet in order to operate their nuclear plants beyond 40 years. In some countries, 40 years is viewed as the end of design life of a plant and continued operation may require very substantial modification. These modifications are not necessarily required because the existing plants are not as safe as they had been for the previous 40 years, but more because of policy decisions that older plants should meet the levels of safety of newer designs. In some countries, policies will make operations beyond 40 years impractical for many plants.

In contrast, most U.S. plants have already received NRC authorization to operate beyond 40 years and many are anticipating operations beyond 60 years. These plants maintain the excellent levels of safety they always have demonstrated and are upgraded continuously based on lessons learned from plant operations in the U.S. and around the world.

While the NRC is still viewed as a global leader, these policy differences are much more pronounced than they have been in the past. That said, the advent of nuclear technologies has considerable potential of resetting many of these regulatory debates. Thus, NRC's review of new designs is being watched very closely around the world.

Senate Committee on Environment and Public Works
Subcommittee on Clean Air and Nuclear Safety
Hearing entitled, *"Advanced Nuclear Technology: Protecting U.S. Leadership and Expanding Opportunities for Licensing New Nuclear Energy Technologies"*
June 4, 2019

Questions for the Record from Senator Braun

3. **What are some of the regulatory approaches used by other nuclear regulatory bodies that in your view, could help develop, license, and deploy advanced nuclear technologies in the United States?**

Response from Director-General Magwood:

I believe the regulations and approaches applied by the Nuclear Regulatory Commission are well-placed to support the development and deployment of advanced technologies. That said, as many have noted, there is a high level of interest by vendors in the staged licencing approach applied by the Canadian Nuclear Safety Commission (CNSC).

I work closely with both NRC and CNSC and note that both regulators will ultimately require very similar analyses and information from applicants in order to approve designs. However, CNSC's Pre-Licensing Vendor Design Review process provides a ready approach to provide vendors with regulatory feedback in three phases: a high-level assessment of the design's compliance with regulatory requirements; an assessment of "potential fundamental barriers" to licencing; and a final phase that allows the applicant to attempt to resolve any problematic findings in the second phase.

This approach is highly favoured by many vendors, and some U.S. companies have chosen to engage the Canadian process instead of submitting applications to the NRC. The Canadian process is of particular interest to small start-up companies that hope to attract investors as they meet with success in the CNSC Pre-Licensing Vendor Design Review process. However, it is important to emphasize that a full review of an application will, by necessity, delve into detailed analyses beyond what is likely in the VDR process. Experience in the U.S. with recent applications demonstrates that the devils are indeed in these details.

That said, while the NRC has the ability to provide early feedback to vendors (and has done so), it does not have a mechanism in place such as the CNSC Pre-Licensing Vendor Design Review and having such a program could provide important benefits.

4. Your position at the OECD gives you a unique viewpoint into international cooperation on these issues.

a. How do you see the NRC's involvement at the OECD?

Response from Director-General Magwood:

The NRC is one of the most important and active nuclear safety regulators in NEA activities. NRC officials often participate in NEA activities and always send excellent delegations to NEA committees and working parties. In recent years, leaders from NRC have chaired important NEA groups, including the previous Executive Director of Operations, who chaired our Committee on Nuclear Regulatory Activities and the previous General Counsel (and current EDO), who chaired our Nuclear Law Committee Working Party on Legal Aspects of Nuclear Safety. Additionally, the Chairman and Commissioners often participate in NEA events.

Also, very importantly, NRC personnel have been better represented among NEA staff who work in Paris than any other U.S. government agency, with four currently on our staff and one more slated to join us in January. This experience benefits both organizations by providing NRC staff with broader experience and exposure to new thinking and providing NEA with some of best nuclear safety expertise in the world. In this vein, I note that the current NRC Director of Nuclear Reactor Regulation was until last year the Head of NEA's Division of Nuclear Safety Regulation and Technology.

We are very appreciative of NRC's engagement and believe that it is supportive of U.S. policy goals, benefits NRC programs and personnel development, and helps support improved nuclear safety worldwide.

b. Are there additional opportunities to engage in OECD-sponsored forums?

Response from Director-General Magwood:

As I noted above, the NRC is a full and vital participant in NEA activities. We do believe that both the NEA and NRC could benefit from a practice of assigning staffs on loan to the NEA for limited-term periods (such as 24 months). Other regulators avail themselves of the opportunity to provide more of their staffs with an international experience and I believe this could be a good practice for the NRC to consider as well.

5. Last month, the Atlantic Council released a report on U.S. nuclear energy leadership which notes that today Russia and China are building more than 60 percent of the globe's new nuclear plants.

a. How do China and Russia view nuclear energy as part of their geopolitical strategy?

Response from Director-General Magwood:

While I have not discussed the geopolitical aspects of nuclear energy with officials of either country, I have discussed with each country their plans and objectives regarding nuclear exports.

Russia's ROSATOM is currently the world's premier exporter of nuclear plants and has active construction projects in several countries, including Bangladesh, Iran, and Turkey with many more in the development stage. ROSATOM has undertaken an impressive program of training for large numbers of personnel from customer and potential customer countries. Many young people from Asia, Africa, and the Middle East are in Russian institutions receiving advanced technical training that they might not otherwise receive. This practice lays important groundwork for long-term cooperative relationships between Russia and many countries.

Chinese organizations, such as China National Nuclear Corp (CNNC) are new to the major global markets for nuclear plants, but are moving very quickly into a strong positon. CNNC, for example, plans to build a Chinese-designed plant in Argentina and another organization, China General Nuclear Power Group (CGN) is financing about a third of the Hinkley Point project in the United Kingdom (which is based on French technology), with full expectation to build a Chinese-designed plant in that country in the coming years.

The ability of both Russian and Chinese organizations to finance nuclear projects is a fundamental advantage as they develop projects around the world. Additionally, both countries have developed excellent nuclear equipment supply chains and very good project management and engineering skills that come with continuous build programs.

It is quite obvious that when one country supplies nuclear plants to another, it establishes very close economic, technical, regulatory, industrial, and political cooperation and relationships that transcend the projects themselves. This, of course, was a central insight of the U.S. Atoms for Peace programs of the 1950s and 1960s.

The success of both Russia and China in their export activities will greatly enhance their relationships with countries around the world as well as strengthening their nuclear industry supply chains and project expertise.

b. What geopolitical risks are presented to the United States if the U.S. does not remain the leader in civilian use of nuclear energy?

Response from Director-General Magwood:

As the U.S. finds fewer opportunities to build nuclear plants, its ability to maintain a healthy nuclear supply chain is reduced, making prospects to successfully build plants at home or abroad more challenging. Further erosion of the U.S. industry increases the possibility that nuclear plants needed in future decades might need to come from outside the U.S.

The ability for any country to supply desired technologies around the world provides a tremendous avenue to influence nuclear safety, non-proliferation, and trade practices. Without products that others desire to build, the ability to influence these practices is greatly reduced.

c. In what ways would further development of advanced nuclear technology in the U.S. help us maintain regulatory and technology dominance?

Response from Director-General Magwood:

I believe that there is a strong prospect for a new wave of nuclear construction around the world if the advanced technologies currently under development—both light water and Generation IV SMRs—prove successful. Many countries that today would not consider building a current technology nuclear power plant may be prime customers for nuclear plants that are smaller, less expensive, easier to build and operate, and feature game-changing safety characteristics.

Such technologies could shift the market entirely—not simply for nuclear technologies, but for energy technologies overall. The country that supplies these technologies would have great influence over how the global market and framework evolves.

Senator BRAUN. Thank you, Mr. Magwood.
Mr. LEVESQUE.

OPENING STATEMENT OF CHRIS LEVESQUE, PRESIDENT AND CHIEF EXECUTIVE OFFICER, TERRAPOWER

Mr. LEVESQUE. Thank you, Chairman Braun, Ranking Member Whitehouse, and members of the subcommittee, for this opportunity to testify. My name is Chris Levesque, and I am the Chief Executive officer of TerraPower, an advanced nuclear technology company based in Bellevue, Washington.

In 2006, our company's founders, Bill Gates and Nathan Myhrvold, began looking for a technological solution to the dual challenges of the growing global demand for energy and the threat of climate change. They discovered the answer is advanced nuclear technology.

My remarks reflect my role as TerraPower's CEO, but also as an engineer, a nuclear navy submarine veteran, and an American who has spent my career working in nuclear energy. From my perspective, it is clear that our Country will lose our leadership in nuclear energy if we fail to innovate and demonstrate the next generation of advanced reactors in the United States.

TerraPower's mission is to approve nuclear energy technology, because it provides reliable, zero-carbon, cost-effective electric and thermal energy. In addition, nuclear power is resilient and can be deployed in the United States and abroad without requiring a natural gas pipeline or a coal train to operate.

Advanced reactors offer next generation safety benefits. In the event of a failure, no human or mechanical intervention is necessary to shut the reactor down. If you were to put these reactors through the Fukushima test, there would be no accident. A fast reactor would shut itself down independently, requiring no human operator action to keep the plant in a safe condition indefinitely.

Advanced nuclear will meet a number of global market needs. Our potential export markets rely on other countries for energy commodities like coal and gas, and all have signed on to the Paris Climate Agreement. The U.N. projects that the demand for nuclear power across the globe could increase as much as five times current levels.

As such, it is not surprising that countries like China and Russia are actively supporting the development of advanced reactors with direct investment by their governments. Some State supported companies sell their reactors and provide fuel, operations and maintenance services and waste services, bringing a multi-decade strategic partnership between the country selling the nuclear reactors and the country purchasing them.

Demonstrating new nuclear technologies is the most important step to jump start an advanced U.S. nuclear industry and compete globally. No company can commercialize advanced nuclear technology until it is demonstrated. Federal support of demonstration efforts has driven down costs for technologies like solar, wind, and hydraulic fracturing. We need a similarly ambitious effort to demonstrate a portfolio of advanced nuclear reactors. This will take increased public-private cooperation, and we need to start this now.

TerraPower appreciates the work of this committee and the Nuclear Regulatory Commission to prepare to license advanced nuclear technology. The enactment of the Nuclear Energy Innovation and Modernization Act, NEIMA, will provide significant help, and we are grateful for your leadership on this legislation.

The recently introduced Nuclear Energy Leadership Act, NELA, provides a robust and important framework. In particular, NELA focuses on the need for public-private partnerships to demonstrate advanced nuclear technologies. We strongly support NELA and hope Congress will move to pass it expeditiously. We want to thank the members of this committee who have co-sponsored it.

However, even without NELA, Congress, through appropriations, can direct the government to develop and fund more coordinated and expedient demonstration activities. We hope to work with you on both to advance demonstration as quickly as possible.

The country that owns advanced nuclear will be a leader in the global nuclear market. Our Country led the world in developing civilian nuclear power, and has decades of R&D experience on a wide range of reactor concepts. Having personally worked on nuclear projects in Europe and Asia, I can attest to how the world looks to the U.S. nuclear industry for our leadership. American deserves to reap the economic and national security benefits created by our innovation and our expertise. With the right public-private partnership and investment, I know we can succeed.

Once again, thank you for the opportunity to testify. I am happy to answer any questions.

[The prepared statement of Mr. Levesque follows:]

Chris Levesque, President and Chief Executive Officer
TerraPower

United States Senate
Committee on Environment and Public Works

Hearing on Advanced Nuclear Technology: Protecting U.S. Leadership and Expanding Opportunities for Licensing New Nuclear Energy Technologies

June 4, 2019

Thank you Chairman Braun, Ranking Member Whitehouse and members of the subcommittee for the opportunity to testify. My name is Chris Levesque, and I am the Chief Executive Officer of TerraPower, an advanced nuclear technology company based in Bellevue, Washington. In 2006, our company's founders - Bill Gates and Nathan Myhrvold – began looking for a technological solution to the dual challenges of the growing global demand for energy and the rising threat of climate change. The answer, they discovered, is advanced nuclear technology. TerraPower has spent more than a decade developing technology that can produce reliable, low-cost, carbon free power to meet those challenges.

The mission of advanced nuclear energy companies like TerraPower is to improve nuclear energy technology on a number of fronts, using the capabilities offered by 21st century technologies and digital modeling previously unavailable. They move well beyond our country's 20th century fleet of light water reactors, including safety improvements, reductions in the risk of weapons proliferation, minimization of waste production, more efficient use of uranium supplies and, eventually, lower costs. TerraPower's goal is to provide a commercial product that provides reliable, zero-carbon, cost-effective electric and thermal energy solutions that can be deployed in the United States and abroad.

Why Invest in Advanced Nuclear Technology?

Nuclear energy solves a broad array of energy and fuel problems. First, like wind and solar, nuclear power is carbon free and can be a key tool in efforts to reduce emissions and pollution. Secondly, like coal and natural gas, nuclear power can provide power 24 hours a day and 7 days a week. But unlike coal and natural gas, nuclear neither emits carbon dioxide or other air pollutants, nor does it require continual delivery of commodities to produce power. The result is always-available, carbon free power that does not require a natural gas pipeline or a coal train to operate. No other form of power has all of these attributes.

We are confident advanced nuclear will meet a number of global market needs. Few potential export markets in the world are as blessed with the kinds of natural resources we enjoy in the United States. Many of these countries rely on international pipelines, rail and ship infrastructure, and relationships with other countries to meet their domestic energy needs. Energy dependence is a serious economic and national security issue for many countries in Europe and Asia. As such, sources of power that require low volume, highly efficient fuel – like advanced nuclear – have great commercial and strategic appeal.

In addition to the economic and national security aspects of nuclear power, every potential export market for American nuclear technology has signed onto the Paris Climate Agreement. The United Nations' Intergovernmental Panel on Climate Change (IPCC) provides a number of pathways to keep global emissions below 1.5 degrees Celsius. None of those pathways allow for a reduction of the share of global power provided by nuclear, and the high economic growth scenario calls for global nuclear power demand to increase by five times current levels.[1] But

[1] https://www.iph/site/assets/uploads/sites/2/2019/02/SR15_Chapter2_Low_Res.pdf

new reactors take time to build and scale, which is why it's imperative to marshal resources and expediently license a portfolio of new reactor technologies.

Given the demand for power generation with these attributes and the global strategic implications, it should not be surprising that other countries are working to develop advanced nuclear technology. Countries like China and Russia are actively supporting the development of advanced reactors with significant direct investment by government into state-supported companies. This direct government support helps these countries establish a valuable export product, but the sale of a reactor also brings important national security benefits for those governments. Some of these state-supported companies sell their reactors with a multi-decade contract to provide fuel, operations and maintenance services, and waste services. This creates a multi-decade strategic partnership between the country selling nuclear reactors, and the country purchasing that technology. Russia, for example, is currently offering these "Build, Own, Operate" contracts in Europe and the Middle East.[2]

Civil nuclear power was invented in the United States, and every advanced nuclear technology under development across the globe was invented in the United States, with support from U.S. taxpayers. Our nation should benefit from that investment, both in terms of the technology we can build to meet our domestic clean power needs, and in terms of the economic and national security opportunity for American companies to sell their products around the world. To achieve these benefits, however, our country needs to make significant investments and a sustained commitment to advance a portfolio of the most promising reactors our country has invented.

What is advanced nuclear, or "Generation IV?"

Generation IV nuclear solutions essentially improve all the critical attributes—efficiency, economics, waste, and safety—compared to the current light water fleet. They allow for greater overall plant efficiency by operating at higher temperatures. This yields carbon-free electricity generation, enables integrated energy systems and larger scale deployment of renewable energy, and provides more heat for industrial applications. A simplified nuclear fuel cycle improves fuel resources and significantly reduces costs and proliferation concerns of waste transportation, storage and disposal.

The costs of nuclear energy include plant construction, operations, fuel and waste treatment. Compared to last century's technology, advanced nuclear designers are developing reactors that will improve the affordability of nuclear energy. Advanced reactors operate at higher temperatures, yielding more electricity and lower costs per kilowatt-hour for the same plant size. Additionally, non-water reactor designs require less maintenance and fuel. Estimated operating costs are about 20 percent less than the current fleet.

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[2] https://www.belfercenter.org/publication/russian-nuclear-energy-proposal-offer-you-cant-refuse

One type of advanced nuclear reactor design allows for smaller fuel purchases at much less frequent intervals. The historic refueling cycle for today's water-cooled reactors is every 18 to 24 months. Advancements, coupled with innovative fuel-coolant combinations, reduce that cycle to once every ten years for certain next-generation technologies. Furthermore, they have the potential to make up to 30 times more energy out of each ton of mined uranium.

Advanced nuclear energy developers are pursuing designs that need less mining, enrichment services and temporary spent fuel storage. Reactors will avoid the costs of building and operating reprocessing plants, as well as the related waste clean-up costs. Some of these new reactors will generate about one-fifth of the waste that today's reactors create.

High energy density uranium produces low volumes of waste compared to other energy sources. Today fission product waste is safely contained at plant sites until they are permanently disposed. These facilities remain under safe control and federal regulation, unlike waste byproducts from other sources of electricity generation. Some advanced reactor technologies generate much smaller amounts of waste enabling new and more efficient approaches to waste disposal. Additionally, many fast reactors can use depleted uranium, typically discarded as a byproduct of enrichment.

Nuclear power also has consistently proven to be the safest way to make electricity. A 2013 paper[3] produced by NASA's Goddard Institute authored by Pushker Kharecha and James Hansen in the journal *Environmental Science and Technology* also supports nuclear power's claim to mitigate health detriments of fossil fuels with the striking figure of 1.8 million as the number of lives saved by replacing fossil fuel sources with nuclear.[4] They estimated the savings of up to 7 million lives in the next four decades, along with substantial reductions in carbon emissions, were nuclear power to replace fossil fuel usage on a large scale. Advanced reactors offer next-generation safety benefits that permit new applications and expand the potential to use nuclear energy for more than electricity production. This new technology will not require active safety systems, eliminating the need for diesel engines, multiple back-up systems and human intervention under emergency scenarios. If you were to put these reactors through the Fukushima test, there would be no accident. A fast reactor would have shut itself down independently, indefinitely.

Some systems avoid high pressure and rely on the natural laws of physics to maintain the safety of the plant without needing operator intervention or auxiliary power, using air and the properties of natural convection, rather than water, as the ultimate heat sink. Safety features in the selection of fuels and coolants provide for enhanced versatility and permit more flexible siting, with a much more compact site and a smaller emergency planning zone within the site boundary.

There also is a long-held concern that civilian nuclear technology could be inappropriately applied for military purposes. Advanced fast reactors substantially lower the risk that key bomb materials – enriched uranium and plutonium – could be diverted to make weapons. This is

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[3] https://pubs.giss.nasa.gov/docs/2013/2013_Kharecha_kh05000e.pdf

[4] https://blogs.scientificamerican.com/the-curious-wavefunction/nuclear-power-may-have-saved-1-8-million-lives-otherwise-lost-to-fossil-fuels-may-save-up-to-7-million-more/

accomplished by consuming the plutonium produced in the reactor as fuel, eliminating the need for reprocessing or using depleted, instead of enriched, uranium as a fuel. This makes the reactor designs we are working on both safe and exportable.

U.S. nuclear technologies and research and development capabilities are envied around the world, and the U.S. enjoys close political and commercial relationships with many countries forged over decades through the construction of U.S.-origin nuclear plants. Exports of U.S. nuclear technology allow the U.S. to set global standards for nuclear security, safety and nonproliferation. The Nuclear Energy Institute points out that reactor exports allow the United States to form 100-year strategic relationships around the world that span the construction, operation and decommissioning of a plant. U.S. nuclear innovators, including TerraPower, have advanced their technology readiness levels sufficiently for early demonstration and offer substantial advances in economics, safety and proliferation resistance. Now is the time to build on the momentum of these innovators.

Meeting Energy Demand in the United States

As noted, advanced nuclear technologies are well positioned to meet market needs throughout the world. But we also see a robust domestic market for our technology. In 2017, nuclear energy generated 20 percent of U.S. electricity and 56 percent of our emissions-free generation, more than all other sources combined. A single nuclear plant produces as much emissions-free electricity as it took to power all electric vehicles in the United States in 2017. Nuclear energy is the only carbon-free electricity source that can provide large, baseload amounts of electricity around the clock. An average nuclear energy facility's life-cycle carbon footprint is comparable to wind, and lower than solar and hydro power plants.

With capacity factors exceeding 90 percent and built to withstand extreme weather – which Is now tested annually as was recently evidenced by recent fires, tornados, hurricanes, and frigid temperatures – nuclear plants generate electricity around the clock when other sources become unavailable. While we've seen a wave of plant closures and as our domestic fleet reaches the end of its licensed life, advanced nuclear designers are developing reactors that can replace reactors as they retire, meet price goals, and lower the overall cost of nuclear energy.

Additionally, as state and federal governments look for ways to expand fuel diversity and reduce pollution and emissions, there will be a market in the United States for advanced nuclear technology. That market will be met either by domestic or foreign reactor companies. In addition to the economic opportunities in the domestic market, for national security reasons, we want our domestic nuclear power needs met by American companies and domestic technology.

The Role of the Federal Government

Unlike many of our foreign competitors, America's advanced nuclear industry is made up of private companies backed by private investors who partner with our national laboratories, research universities, and agencies, like the U.S. Department of Energy, to develop domestic advanced nuclear technology.

As this committee knows well, nuclear energy is an industry that is heavily regulated, posing significant uncertainly to reactor developers, is very capital intensive and requires access to sophisticated facilities, test reactors, and equipment. These challenges pose significant risks to recouping a return on investment and thus inhibit investment, particularly when scaling-up new nuclear technologies. The U.S. government has a key role to play in reducing these risks, providing direct support, and removing barriers to research, development and deployment to ensure the United States remains a leader in nuclear energy technologies.

TerraPower appreciates the work of both this committee and the Nuclear Regulatory Commission (NRC) to prepare for the licensing of advanced nuclear technology. The enactment of the Nuclear Energy Innovation and Modernization Act (NEIMA) will provide significant help, and we are grateful for your leadership and work on that legislation. We look forward to continuing to work with the NRC on implementing NEIMA and licensing advanced reactors.

Beyond the NRC, advanced reactors will need the support of the DOE and our national lab complex. Our national labs are a national asset and are vital to industry to develop, test, and deploy new technologies. TerraPower has established strong technical relationships and jointly beneficial partnerships with the labs. Public-private partnerships with the national laboratories have led to rapid and significant progress on the research and development of advanced nuclear technologies. But the primary goal needs to be the commercialization of advanced reactor technologies that can meet the demand for reliable, clean, scalable, and affordable power. The next, and most important, challenge will be developing a system to demonstrate those technologies to meet both domestic and global market demands in a time frame that matters. We are encouraged by discussions and activities that are happening in the U.S. federal government to support the demonstration of advanced nuclear technologies.

On this front, TerraPower believes one of the most important tools in that discussion is S. 903, the recently introduced Nuclear Energy Leadership Act (NELA). This legislation presents a vision and execution strategy with specific targets and milestones to advance the nuclear industry, including, advanced reactor research goals, a fast neutron test facility along with high-assay, low-enriched uranium for research and the demonstration of several advanced nuclear reactors. We appreciate that a number of members of this committee have joined as co-sponsors of this important bill and we hope Congress will move to pass NELA expeditiously. However, even without NELA, the federal government can move to develop and fund more coordinated and expedient demonstration activities for those companies ready to graduate from the R&D phase.

I want to stress that the need for demonstration is critical—for TerraPower specifically but also for the advanced nuclear community generally. No company can commercialize advanced nuclear technology and bring down costs until it is demonstrated. In the near-term, the only way to kickstart the advanced nuclear industry is to demonstrate a portfolio of reactors. Demonstrating multiple reactors will not only validate new designs, but also will enable companies to establish supply chains, bring down costs and begin to scale—all of which will

bring economic, employment, and environmental benefits. There are several analogies that give us confidence that we can accomplish this in partnership with the U.S. government. Recall solar energy's start was not affordable; solar energy became affordable through cost curves driven by government funded RD&D, deployment policies like the Loan Programs Office, and robust growth in commercial markets that led to new learnings, innovations, and considerable cost reductions through manufacturing improvements. We need a similarly ambitious effort to move advanced nuclear forward.

Conclusion

The country that owns the advanced nuclear transition will be a leader in the global nuclear market and fulfill the international goals of deploying clean energy, supporting energy security, lifting millions out of energy poverty, and driving economic growth. The nuclear industry is critical to providing the safe and clean baseload power the world will require over the coming century.

The United States is sitting on a massive opportunity to build out and own the advanced nuclear industry, and the benefits are clear. The U.S. has a great history of innovation. Our country led the world in developing civilian nuclear power since the 1950s and has decades of R&D expertise on a wide range of reactor concepts. The U.S. deserves to reap the economic and national security benefits created by that innovation and expertise. With the right public private partnership and investment, I know we can.

Additional Information

American Energy Innovation Council Report – Energy Innovation: Fueling America's Economic Engine[5]

Third Way Report on Advanced Nuclear Industry [6]

TerraPower Co-founder and Vice Chairman Nathan Myhrvold Op-Ed on Nuclear Energy Innovation[7]

[5] http://americanenergyinnovation.org/wp-content/uploads/2018/11/Energy-Innovation-Fueling-Americas-Economic-Engine.pdf
[6] https://www.thirdway.org/graphic/keeping-up-with-the-advanced-nuclear-industry
[7] https://www.intellectualventures.com/buzz/insights/why-we-need-innovative-nuclear-energy

Senate Committee on Environment and Public Works
Subcommittee on Clean Air and Nuclear Safety
Hearing entitled, *"Advanced Nuclear Technology: Protecting U.S. Leadership and Expanding Opportunities for Licensing New Nuclear Energy Technologies"*
June 4, 2019
Questions for the Record for Mr. Chris Levesque, CEO, TerraPower

Chairman Barrasso:

1. Establishing a common set of technical information for different national nuclear regulatory would help deploy advanced nuclear technologies. It could save time and money for nuclear companies seeking to license and deploy advanced nuclear technologies around the globe. Would a multi-national initiative to establish common information sets for licensing advanced nuclear technologies help TerraPower engage internationally in a more timely and cost-effective manner?

A multi-national initiative to establish common information sets for licensing advanced nuclear technologies would help TerraPower and other advanced reactor developers engage more time and cost efficiently internationally. Some efforts have already been initiated to establish common design requirements and common regulatory standards for licensing advanced nuclear technologies.

The NRC has published common design requirements. The Electric Power Research Institute (EPRI) has developed a common set of requirements called Owner-Operator Requirements Guide (ORG) to reflect expectations and needs of prospective owner-operators for advanced nuclear reactor designs.

When advanced reactors are ready for deployment, it would be beneficial if there were common regulatory standards developed in advance of their deployment. The International Atomic Energy Agency (IAEA) and the Generation IV International Forum (GIF) may be able to provide coordination. GIF has initiated efforts that will help in the development of common regulatory standards for different national nuclear regulatory frameworks. The Multinational Design Evaluation Programme (MDEP) was launched to develop multinational regulatory standards for design of Generation IV reactors. GIF has worked with experts from the IAEA in this topical area. The IAEA is the world's central intergovernmental forum for scientific and technical co-operation in the nuclear field.

In summary, a multi-national initiative to establish common design requirements and common regulatory standards would help bring advanced reactor developers, supplier nations, and purchasing countries into a common understanding on how to license advanced reactors internationally. Efforts have been initiated to develop international safety standards and international regulatory standards. These would help TerraPower and other advanced reactor developers engage more time and cost efficiently internationally.

A recent Atlantic Council report cites, "Hence, international cooperation with US leadership on development of standards for advanced reactors is extremely important for safety and security and for setting a level playing field where all parties can compete."

2. How do different international nuclear regulations limit your ability to predictably and efficiently navigate a global nuclear market?

When a license application is submitted to a nuclear regulator, the nuclear regulator will determine whether the applicant has met the regulatory requirements for that country. Regulations may differ from country to country and can result in different standards for quality assurance and operational performance.

If reactor design and analyses differ from country to country, the future of nuclear energy will lack the consistency achieved by groups like the WANO and INPO among the existing fleet of light water reactors. Long term, the lack of international nuclear regulations for advanced reactors has not been evaluated and therefore cannot be effectively addressed and incorporated early in advanced reactor designs. For these reasons, the ability to predictably and efficiently navigate a global nuclear market is limited.

3. How would American jobs and the economy be impacted if American nuclear companies, such as Terrapower, lead the global deployment of advanced nuclear technologies?

According to a Nuclear Energy Institute fact sheet, nuclear presently supports 475,000 jobs (100,000 direct and 375,000 secondary jobs) and adds $60B to the U.S. GDP.
https://www.nei.org/CorporateSite/media/filefolder/resources/fact-sheets/nuclear-by-the-numbers.pdf

NEI provides the following facts on nuclear industry jobs https://www.nei.org/advantages/jobs

- *Each nuclear power plant employs 400 to 700 workers.*
- *Building a nuclear power plant employs up to 3,500 workers at peak construction.*
- *The typical nuclear power plant creates $40 million in labor income each year.*
- *For every 100 nuclear power plant jobs, 66 more jobs are created in the local community.*
- *Contributes $10 billion in federal and $2.2 billion state taxes*

The U.S. Department of Commerce has estimates that over the next decade, the nuclear industry has the potential to "generate more than $100 billion in U.S. exports and thousands of new jobs."
https://www.selectusa.gov/energy-industry-united-states

Senator Braun:

4. Last month, the Atlantic Council released a report on U.S. nuclear energy leadership which notes that today Russia and China are building more than 60 percent of the globe's new nuclear plants.

    a. How do China and Russia view nuclear energy as part of their geopolitical strategy?

As new countries embrace new generations of nuclear technology, historic nuclear operators like the U.S. lose their competitive edge. New nuclear construction is a geopolitical strategy for the unique know-how and expertise each new facility produces. With growing construction and operational experience, embarking countries will go to Russia/China and not the U.S. for long-term products and services.

According to a World Nuclear Organization Report (https://www.world-nuclear.org/getmedia/b392d1cd-f7d2-4d54-9355-9a65f71a3419/performance-report.pdf.aspx) *China is considered to be dominating global civil nuclear development and construction. The strength of their domestic nuclear sector supports nuclear technology trade internationally. Russia is also negotiating numerous nuclear deals internationally. These transactions are negotiated between state-owned entities and often include finance packages in addition to construction and operations. We know that bilateral relationships at this level are longstanding and strategic and produce significant exports and support jobs but also enable geopolitical influence.*

https://www.thirdway.org/report/getting-back-in-the-game-a-strategy-to-boost-american-nuclear-exports

    b. What geopolitical risks are presented to the United States if the U.S. does not remain the leader in civilian use of nuclear energy?

The United States has long been a leader in civilian nuclear development and trade. New nuclear deployments run into the billions of dollars (USD) and employ tens of thousands of workers. As U.S. market share declines so will our influence on international security. The U.S. Department of Commerce estimates the global civil nuclear market to be valued between $500 and $740 billion over the next ten years and to have the potential to generate more than $100 billion in U.S. exports and thousands of new jobs (https://www.trade.gov/topmarkets/pdf/Civil_and_Nuclear_Top_Markets_Report_2017.pdf). *Civil nuclear trade has provided benefits to our foreign policy, economy, and brought with it the strong safety and safeguards of nuclear power. Further, the Atlantic Council's recent report on U.S. nuclear energy leadership states that a dwindling nuclear supply chain and its associated reduction in talent capabilities including knowledge and expertise in civilian nuclear power, adversely impacts the provision of services to the U.S. military.*

c. In what ways would further development of advanced nuclear technology in the U.S. help us maintain regulatory and technology dominance?

With nearly 1 billion people globally without access to electricity, providing carbon free nuclear energy will raise living standards without further harming the environment. U.S. technology leadership further fosters the highest standards for nuclear safety and nonproliferation. The objectives of trade and jobs, economic and energy security and foreign policy and influence are promoted through U.S. regulatory and technology leadership in peaceful civil nuclear.

With the previous leadership of the United States in nuclear energy, nuclear regulation, together with the strength of our domestic technology innovation, the United States should lead in bringing advanced nuclear to market. Doing so will take considerable public and private funding to unleash the economic, environmental and strategic rewards.

Senator BRAUN. Thank you, Mr. Levesque.
Mr. PERCIASEPE.

OPENING STATEMENT OF HON. BOB PERCIASEPE, PRESIDENT, CENTER FOR CLIMATE AND ENERGY SOLUTIONS

Mr. PERCIASEPE. Thank you, Mr. Chairman and Ranking Member, and Mr. Ranking Member of the full committee.

I am honored to be here with all of you. It has been a while since I have been in this room. I have great memories of confirmation hearings.

This is a pretty important subject, and I think the opening comments by the members were right on target, really important issues. You had mentioned my experiences in the past. I am currently the President of the Center for Climate and Energy Solutions, which is an organization that looks at global climate, and we are recognized and trusted as a pragmatic and wise counsel on technologies and on technology-inclusive approaches.

The climate change challenge is another one of the important contexts for this conversation. Decarbonizing U.S. energy is a pretty significant task. We need to get to at least 80 percent by the middle of the century, and we are currently about 11 percent less than we were in 2005. Current nuclear power is at 50 percent of that zero-emitting electricity.

Decarbonizing electricity is on the critical path for decarbonizing our economy and for meeting our mid-century goals for climate change. Virtually all the analysis that has been done in the Intergovernmental Panel on Climate Change, the U.S. Climate Assessment, all of them show that the long-term need for zero-emitting energy is looking at all the different technologies together, as the least technically challenging, but also the least-cost path to decarbonization. The value of the existing nuclear fleet is pretty important. It is 20 percent of our total electricity, but it is also 50 percent of our clean electricity. Emissions will increase if the existing nuclear fleet retires prematurely.

The other important part of the existing nuclear fleet, they are the foundation and the technical capacity for many of the issues that the previous witnesses discussed. And keeping the existing facilities going will also buy time needed for the additional innovation for advanced nuclear, deployment of advanced renewable technologies and innovation with carbon capture.

There is a simple math here that we have pointed out in a number of our publications, that, if you need to get to 80 percent and your current situation is, you have about 10 percent from renewable—I am rounding the numbers here, so these are not precise—and 20 percent from nuclear, that is 30 percent of our electricity coming from clean and non-emitting sources. But if you triple those renewable sources over the next 15 to 20 years, and you lose the nuclear, you are back at 30 percent, 20 years down the road, on that.

I want to commend the committee for the work they have done on NEIMA and the work they are doing on NELA. These are really important pieces of legislation. They are sending really important signals to people like Chris. Our view is there are over 50 companies out there that are working on advanced nuclear strategies,

and also probably close to a billion dollars in private capital somehow involved with that.

Some of the actions that have been taken to preserve the existing nuclear, and I want to be clear, preserving the existing nuclear preserves our intellectual capacity, which sends the right signal to the advanced nuclear industry, which sometimes are interspersed. So Senator Whitehouse mentioned the market failures of these facilities not being compensated for their zero emissions. Several States, and I will mention New York, New Jersey, Hawaii, Connecticut, are States who have moved ahead to put together zero emissions credits to provide compensation for the zero-emission work. And it sends signals to the innovators. That has changed the trajectory of eight different plants, and has saved us 33 million metric tons of carbon.

There are Federal approaches also, including the work that you all have done on NEIMA, and the work that you continue to do. Market signals for zero emissions is always good, carbon fees, capital investments by the Federal Government, clarity on new paths for permitting, for new technologies, clarity on extending licensing on existing facilities.

And an even bigger picture I want to mention, which has already been mentioned, I also served on the task force for nuclear energy leadership at the Atlantic Council. Really, maintaining the existing fleet, catalyzing innovation and being a nuclear power exporter is really in the strategic interests of the United States. Being on that task force enabled me to look at both of these climate issues, but also the global strategic issues that are involved.

So I will stop there. Sorry, I went over a few minutes.

[The prepared statement of Mr. Perciasepe follows:]

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

Hearings before the Subcommittee on Clean Air and Nuclear Safety of the Senate Committee on Environment and Public Works

Testimony of

Robert Perciasepe, President at the Center for Climate and Energy Solutions (C2ES)

June 4, 2019

Background

Good morning, I am Bob Perciasepe, the president of the Center for Climate and Energy Solutions (C2ES). Before joining C2ES, I was most recently the Deputy Administrator of the U.S. Environmental Protection Agency (EPA) from 2009 through 2014. Before that, I was the chief operating officer for the National Audubon Society and also the Secretary of Maryland's Department of Environment. A full biography is attached and submitted for the record.

The organization I now lead, C2ES, is the successor to the Pew Center on Global Climate Change, which was founded in 1998 and is widely recognized as an influential and pragmatic voice on climate issues. Our mission is to advance strong policy and action to reduce greenhouse gas emissions, promote clean energy, and strengthen resilience to climate impacts. A key objective is a national market-based program to reduce emissions cost-effectively. We believe a sound climate strategy is essential to ensure a strong, sustainable economy.

Our view is that in the long-term, a national market-based program to encourage a lower-carbon economy is the best approach to achieve the needed reductions in emissions. In the near-term, state leadership is essential to maintaining our existing nuclear fleet as we make this transition to a cleaner energy future. We view nuclear power as a vital element in a low carbon economy. In short, I and my organization have come to the unescapable conclusion that preserving the existing U.S. nuclear reactor fleet for as long as possible is a critical element in the transition to a low-carbon future. These units are just too big and too clean to replace quickly. States with the advantage of existing nuclear capacity should take reasonable steps to prevent the premature retirement of these essential clean energy sources while federal, regional and additional state policies are being developed to facilitate clean energy technologies like renewables, energy efficiency, energy storage, advanced nuclear, and fossil fuel-fired electricity using carbon capture and storage.

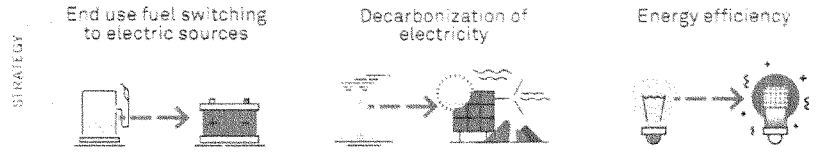
Nuclear power has been providing a significant environmental benefit for decades; society and markets, in most instances, are not valuing that. We know that we need to deeply decarbonize global energy production. In the U.S., we need to reduce emissions across the entire economy (not just in the power sector) by at least 80 percent by 2050, to help stave off the worst effects of climate change. And, just about all of the modeling that has been done to date shows that we need nuclear power, renewables and carbon capture and sequestration to achieve that kind of massive, economy-wide emission reduction.

Nuclear's Role in the Energy Transition Challenge

Decarbonizing the United States' energy system is a monumental task. It will require reducing our greenhouse gas emissions 80 percent or more by mid-century to avoid the worst impacts of climate change. To date, the U.S. has only managed to reduce its net emissions a little more than 13 percent below 2005 levels. That leaves a significant margin yet to account for.

In order to meet the 2-degree Celsius (3.8-degree Fahrenheit) target agreed to by the international community and avoid the worst effects of climate change, global net greenhouse gas emissions must be approaching zero by the second half of this century.[1] Pathways to deep decarbonization generally focus on three, equally important activities: (1) end-use fuel switching, primarily to electric sources (e.g., switching from gasoline- and diesel-powered to electric vehicles), (2) decarbonization of the electric power sector, and (3) increasing deployment of energy efficiency.[2] There are many possible ways to decarbonize the power sector. However, most studies indicate that a diverse mix of renewables, nuclear power, and fossil fuel with carbon capture utilization and storage is the least cost and least technically challenging path to achieve the mid-century goal.[3]

Figure 1: Three Pillars of a Clean Energy Economy



Source: Risky Business Project, From Risk to Return: Investing in a Clean Energy Economy.

In order to accelerate the rate of decarbonization, we will need breakthroughs in technology accompanied by strong policy signals for businesses to innovate.

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[1] IPCC, "Summary for Policymakers," in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (Cambridge, United Kingdom: Cambridge University Press, Cambridge, 2014), https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf.

[2] Risk Business Project, *From Risk to Return: Investing in a Clean Energy Economy* (Ricky Business Project, 2016), https://riskybusiness.org/fromrisktoreturn.

[3] Jesse Jenkins and Samuel Thernstrom, *Deep Decarbonization of the Electric Power Sector Insights from Recent Literature* (Arlington, VA: Energy Innovation Reform Project, 2017), http://innovationreform.org/wp-content/uploads/2017/03/EIRP-Deep-Decarb-Lit-Review-Jenkins-Thernstrom-March-2017.pdf.

Entrepreneurs, engineers, and investors are working to develop a wide range of advanced nuclear reactor designs. In the United States and Canada, nearly 50 companies backed by more than $1 billion in private capital are working on these plants.[4]

Advanced reactors can dependably generate zero-emission electricity and useful heat, and they are scalable to produce large quantities of energy from a very small footprint. New designs hold the promise of being more affordable, even safer, and are expected to produce less waste than the current generation of reactors.

The recently adopted Nuclear Energy Innovation Capabilities Act (NEICA), which went through the Energy and Natural Resources Committee, directs DOE to prioritize partnerships with private innovators to test and demonstrate advanced nuclear reactor concepts. It authorizes the creation of a National Reactor Innovation Center to combine the technical expertise of the National Labs and DOE to enable the construction of experimental reactors.

Additional support in the area of modernizing the licensing process for advanced reactors from the recently reintroduced Nuclear Energy Innovation Modernization Act (NEIMA) will also be critical to support the timely development of advanced reactor technology, as it will create greater certainty for developers and investors.

Modeling to date clearly shows that we need nuclear power, renewables, carbon capture, and improved energy efficiency to achieve large-scale, economy-wide emission reductions. It is absolutely necessary to pursue all promising zero-emissions technologies with equal vigor.

Importantly, existing nuclear power plants are a critical bridge to our advanced nuclear future. Keeping the U.S. nuclear fleet in place for as long as practical helps avoid backsliding in emissions, helps maintain our domestic nuclear expertise, and buys us the critical time necessary to develop, deploy and commercialize the next generation of nuclear reactors and other zero-emission technologies.

NEICA and policies like it will help to speed the development process and spur the kind of innovation that we will need to provide a cleaner second half of the century.

With thoughtful leadership, this step proves bipartisan backing exists for solutions to support the development of clean technologies like advanced nuclear, carbon capture, energy storage, and others – even in a challenging political environment. To meet our climate and clean energy goals, we must seek stable solutions that endure political transitions and maintain an ambitious pace to reduce emissions – and NEICA is an encouraging sign that there are potential partners for cooperative action.

Value of existing nuclear plants to completely decarbonizing the electric power sector

The existing nuclear fleet provides more than half of the United States' zero-emissions electricity that is simply not replaceable quickly. We have uniformly seen, with premature nuclear retirements, the lost emission-free power was substantially replaced with coal or natural gas. This increased emissions of CO_2 as

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[4] Samuel Brinton, *The Advanced Nuclear Industry* (Washington, DC: Third Way, 2015), https://www.thirdway.org/report/the-advanced-nuclear-industry.

well as traditional air pollutants that contribute to smog and other serious public health impacts. Looking at in-state power sector CO_2 emissions in the year before and the year after nuclear power plant closures for these three states:

- Wisconsin saw a 2.6 million metric ton increase,
- Florida saw a 2.7 million metric ton increase, and
- California's saw a 9.6 million metric ton increase.

In response to the substantial emissions increases that followed the closure of San Onofre, the State of California is in the process of procuring energy efficiency and renewable energy to replace the 2,256 MW Diablo Canyon Nuclear Power Plant, currently scheduled to close over the 2024-25 timeframe.[5] Replacing this zero emitting power will essentially get the State back to where it is today, emissions-wise. This is a key observation: **early nuclear retirements lead to increased emissions and many years of alternative clean energy development, just to get back to where the state started,** and during that time, the atmosphere received many millions of tons of carbon dioxide that will be there for centuries.

Last year, Florida Power & Light became the first operator to apply to the Nuclear Regulatory Commission (NRC) for a second license renewal (SLR) for its Turkey Point plant in South Florida.[6] An SLR will bring the total operational lifetime of a reactor to 80 years. In addition to avoiding carbon dioxide emissions further into the future, extending a nuclear plant's life creates additional opportunities. Plant operators are more likely to consider performing maintenance (e.g., turbine upgrade) activities that would not have otherwise been considered for a plant planning to retire in a few years, which would further improve the efficiency of the nuclear power plant. Thereby avoiding even greater quantities of carbon dioxide emissions.

Renewables and nuclear are needed

Maintaining existing reactors and potentially running them longer (i.e., perhaps up to 80 years) and improving their efficiency avoids backsliding in emissions in the short- and medium-term. In the long run, it also buys time to deploy greater quantities of renewables, energy efficiency, energy storage, advanced nuclear and fossil fuel-fired electricity using carbon capture and storage.

The mid-century decarbonization challenge is daunting. U.S. electricity demand growth has largely flat-lined over the last decade. The drivers of this trend have been upgrading to more efficient equipment, implementing efficiency standards (light bulbs and appliances), slowing population growth and a shift away from energy-intensive industries to a more service-oriented economy.[7] However, in the mid- to long-term, assuming deep decarbonization policies are put in place, electricity generation nationally could increase by

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[5] In 2018, California derived 45 percent of its in-state electricity generation from carbon-emitting sources (i.e., natural gas) and 8 percent from nuclear power, U.S. Energy Information Administration, 2019.

[6] Aaron Martin, "Florida Power & Light applies for second license renewal for Turkey Point nuclear reactors," Daily Energy Insider, February 5, 2018, https://dailyenergyinsider.com/news/10502-florida-power-light-applies-second-license-renewal-turkey-point-nuclear-reactors/.

[7] U.S. Energy Information Administration, *Annual Energy Outlook 2017 with projections to 2050* (Washington, DC: U.S. Energy Information Administration, 2017), https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf.

more than 75 percent by 2050, as we see greater deployment of electric vehicles, electric heat pumps for home heating and cooling, electric boilers in industry, and many other areas of end-use electrification.[8] Most scenarios show very large increases in renewable generation and that nuclear power has an even larger role to play (to meet this increased level of consumption) in the future electricity generation mix.[9]

We need to ensure that the existing nuclear fleet remains in place for as long as practical to help support a more electrified future. However, six plants have retired since 2013, two plants are scheduled to shut down this year (2019), and an additional six plants will close by 2025. Not all reactors will run for 80 years; some are unlikely to run for 40 years due to short-term economic challenges. However, most profitable facilities are expected to apply for the SLRs. Zero-emission technologies like small and advanced nuclear reactors would have a clear role to play as the size of the power market grows and in replacing retiring plants.

Benefits, Challenges and Opportunities of Nuclear Power

In addition to the climate benefit of avoided carbon dioxide emissions:

- Nuclear is dispatchable and extremely reliable – most plants run 24 x 7 for 18 to 24 months, stopping only for refueling and routine maintenance during the refueling outage.
- They are an important provider of fuel diversity.
- Nuclear power is also extremely energy dense, so it has a very small footprint. For example, three reactors in southern New Jersey (Hope Creek and Salem) provide 40 percent of the state's annual electricity using only a 1.15 square mile footprint.
- Also, they don't contribute to air pollution or acid rain.
- And, they provide good rural jobs.

As for the challenges:

- Many nuclear power plants are reliant on revenue from wholesale power markets.
- Power market prices are at all-time historic lows, primarily due to very low natural gas prices.
- Reactors are not overly expensive to operate, but market revenue (energy and capacity payments) are not sufficient.
- One-third of plants are unprofitable; other estimates say it may be as many as one-half.
- Finding a long-term waste storage solution is also a challenge.

A few opportunities exist:

- Deep decarbonization policies will likely lead to a substantial increase in electric power generation, perhaps a doubling or more by 2050, as we see greater deployment of electric vehicles, electric heat

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[8] White House Council on Environmental Quality, *United States Mid-Century Strategy for Deep Decarbonization* (Washington, DC: White House, 2016), https://unfccc.int/files/focus/long-term_strategies/application/pdf/mid_century_strategy_report-final_red.pdf.

[9] Jesse Jenkins and Samuel Thernstrom, *Deep Decarbonization of the Electric Power Sector Insights from Recent Literature.*

pumps for home heating and cooling, electric boilers in industry, and many other areas of end-use electrification.

- And, with greater quantities of variable renewables on the grid, excess generation from nuclear power and/or renewables could produce hydrogen for long-term energy storage – which could be used as fuel for power plants or vehicles.
- Also, new business opportunities exist. Nuclear could provide process heat for creating fresh drinking water, other industrial processes or even district heating.

Key Findings from our May 2018 Report

The key message from our May 2018 report is that targeted state policies, particularly "zero emission credits" or ZEC programs, are the best option right now for existing reactors, as states are able to relatively quickly adopt measures that directly support distressed facilities. For those who are not familiar with ZEC programs, eligible nuclear generation facilities get a credit for each zero-emission MWh of generation they produce. In Illinois and New York that is currently worth around $17/MWh.

From the environmental perspective, these subsidies are defensible. We see a clear failure in power markets. The market was designed for least cost dispatch and reliability. Therefore, generators can currently emit as much carbon dioxide as they'd like, without a cost. The ZEC transparently offsets this market failure and rewards a nuclear generator for its environmental benefit.

ZEC programs have passed in state legislatures with bipartisan support by forming a broad coalition, which has included labor groups, renewable energy interests, and environmental justice groups.

There is a growing appreciation that when a nuclear power plant closes that it is being replaced by fossil fuel-fired generation, which is increasing a state's emission profile. And, recent reports from the Intergovernmental Panel on Climate Change and the Fourth National Climate Assessment demonstrate that we cannot afford emissions backsliding and that climate change is here and now.

As a result of ZEC programs and other targeted policies in New York, Illinois, New Jersey, and Connecticut, those states have, for now, averted the closure of eight plants. Those plants have around 11.8 GW of capacity and help avoid 33 million metric tons of carbon dioxide emissions annually – which is the equivalent of taking 7 million cars off the road every year.

It is encouraging that ZEC policies are up and running and have withstood legal challenges in in New York and Illinois.

Converting a state renewable portfolio standard into a clean energy standard is another state level policy that can help the existing fleet.

Increasingly, states like California, New York, and New Jersey are raising the ambition of their clean energy targets, which leaves the door open for all non-emitting electricity sources.

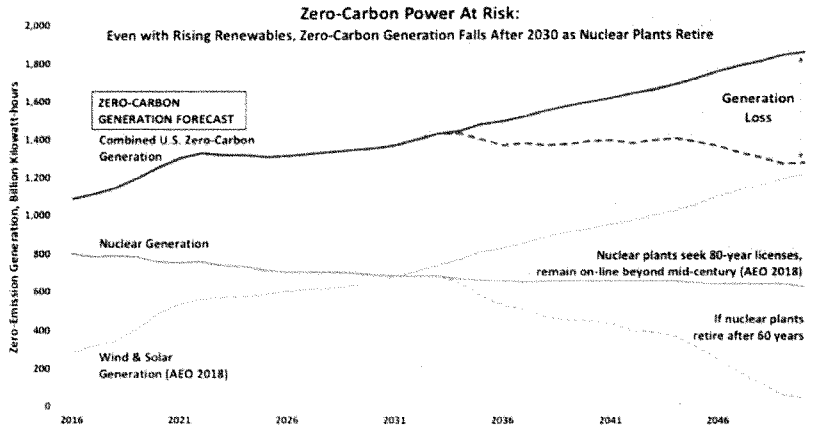
Federal Level Action that Could Help Nuclear Power

Federal-level action from Congress or federal agencies could help nuclear power as well:

- Carbon-pricing (either a tax or a cap-and-trade program) could help nuclear, but the carbon price would have to be significant in order to matter.
- Tax credits for capital expenditures at nuclear plants is another idea that could help.
- Establishing a national clean energy standard, like the one recently proposed by Senator Tina Smith of Minnesota, would also benefit nuclear power.
- Another idea is a federal ZEC program, which could be more far reaching than individual state programs.
- Reforming wholesale power markets (FERC) could also help. For example, in New York state, which have already established a ZEC program, the New York ISO (i.e., the wholesale power market for the state) is looking into adding a carbon price into its market.

Why We Need a Zero-Emission Coalition

Figure 1: Power Generation Trends to 2050



This chart demonstrates why we need a zero-emission coalition – or an all-of-the above approach for zero-emitting technologies.

The chart uses the generation forecast for nuclear power and wind and solar from the U.S. Energy Information Administration's (EIA) "Annual Energy Outlook 2018."

The green line is the forecast for wind and solar generation from 2016 until 2050.

The EIA projects that wind capacity will increase by around 70 percent and solar capacity will be 11 times greater by 2050, producing together around 4 times the amount of electricity or more than 1,200 billion kilowatt-hours.

The solid orange line is the forecast for nuclear generation from 2016 until 2050.

The EIA has included known plant retirements, but it also assumes that the remaining reactors will operate for up to 80 years.

If that holds true, then combined U.S. zero-carbon generation, the solid gray top line, will continue to grow to 2050.

If, however, nuclear plants retire at 60 years, as reflected in the dashed orange line, then the total of U.S. zero-carbon generation will peak around the mid 2030s, flat-line, and potentially even decline into mid-century.

This is not a pathway to deeply decarbonize our power sector.

- This is why we are saying that we need nuclear and renewables, not renewables attempting to replace nuclear power for decades.[10]
- Of course, regulators at the NRC can help extend the life of the existing fleet by approving subsequent license renewals, allowing plants to operate for up to 80 years. This process has begun.
- This would buy us valuable time to deploy more renewables, advanced nuclear and carbon capture and storage before mid-Century.

Energy Efficiency

Increasing energy efficiency is a key strategy in achieving deep decarbonization. It is often said that the cheapest kilowatt is the one that is never used. Setting annual energy savings goals will provide numerous benefits over time. Energy efficiency will help to reduce costs for consumers and reduce the total amount of power generation capacity that needs to be built to support a decarbonized economy (saving ratepayers even more money over time).

We believe that a broad-based approach is the best approach. We need energy policies that preserve existing nuclear, expand renewables, and promote other advanced zero-emission technologies, and we need to implement aggressive energy savings targets to put us on the pathway to 100 percent clean energy by mid-century.

Value of Existing Nuclear Generation to Climate and Air Quality

Nuclear power is by far the largest source of zero-emission power in the United States (see Figure 2). The Center for Climate and Energy Solutions was somewhat neutral on the fate of nuclear energy for many years,

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[10] A recent report from the International Energy Agency (IEA) highlights this point on a global scale. See International Energy Agency, *Nuclear Power in a Clean Energy System* (Paris, France: International Energy Agency, 2019), https://webstore.iea.org/nuclear-power-in-a-clean-energy-system.

but in this past decade we have conducted several reviews of pathways to low-carbon electricity. **Our key publications in 2014 and 2018 found that the goals of significant reductions in greenhouse gas emissions over the next three decades would be severely handicapped if the zero-emissions from nuclear power had to also be compensated for rather than built on.**[11] [12] [13] C2ES has revised its view from neutral to seeing the preservation of existing zero emissions resources, including nuclear, as an irreplaceable **foundation**.

The existing nuclear fleet has enhanced its capacity greatly in the last two decades. Since 1990, nuclear has consistently supplied around one-fifth of U.S. electric power generation, even while total generation increased 33 percent, largely through power uprates (plant modifications that increase the electrical output of existing reactors), shorter refueling outages, and other efficiency improvements. Uprates alone have added over 6,000 MW of emission-free generating capacity since 1977.

The 99 currently operational reactors help avoid the emission of 320 million to 578 million metric tons of carbon dioxide each year. These numbers can seem too large to comprehend – for scale, these avoided emissions equal between one-fifth to one-third of the current emissions of the entire fossil-fired portion of the electric generating sector in the U.S.[14] This means that premature retirement of any reactors make it tougher to meet air pollution, emissions and climate goals.

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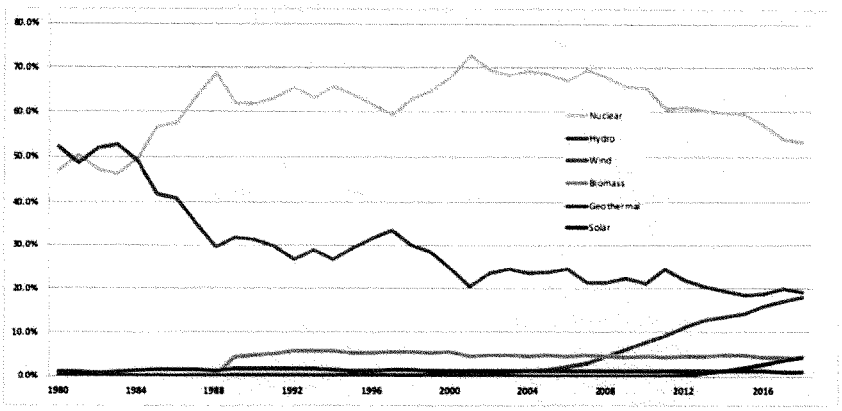
[11] Doug Vine and Timothy Juliani, *Climate Solutions: The Role of Nuclear Power* (Arlington, VA: Center for Climate and Energy Solutions, 2014), https://www.c2es.org/site/assets/uploads/2014/04/climate-solutions-role-nuclear-power.pdf.

[12] Doug Vine, *Solutions for Maintaining the Existing Nuclear Fleet* (Arlington, VA: Center for Climate and Energy Solutions, 2018), https://www.c2es.org/site/assets/uploads/2018/05/solutions-for-maintaining-existing-nuclear-fleet.pdf.

[13] Judi Greenwald and Doug Vine, *Promising Market and Federal Solutions for Existing Nuclear Power* (Arlington, VA: Center for Climate and Energy Solutions, 2018), https://www.c2es.org/site/assets/uploads/2018/10/promising-market-and-federal-solutions-for-existing-nuclear-power.pdf.

[14] "How much of U.S. carbon dioxide emissions are associated with electricity generation?" U.S. Energy Information Administration, last modified May 15, 2019, https://www.eia.gov/tools/faqs/faq.php?id=77&t=11.

Figure 2: Zero-Emission Fuel Sources for Electricity Generation, 1980–2018



Nuclear plants prevent substantial emissions of CO_2, SO_2, NO_X, particulate matter and the formation of ozone, compared to the alternative of natural gas and coal-fired generation that would most likely replace their output.

Nuclear Power and National Security

A recent report issued by the Atlantic Council, to which Senator Sheldon Whitehouse was an honorary co-chair, and where I was a member of the task force, found that the U.S. civilian nuclear power industry is a strategic asset of vital importance to U.S. national security. However, it is facing a serious challenge to its historical leadership in the global civilian nuclear power market, particularly from Russia and China.[15]

To quote the report, "The Task Force found that a flourishing domestic nuclear energy sector is critical to U.S. national security, both in the interconnections between military and civilian uses of nuclear energy, as well as in foreign policy. This report recommends maintaining and expanding the current nuclear fleet; creating a conducive regulatory environment for innovation and new technologies; and encouraging and facilitating nuclear energy exports."

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[15] Atlantic Council Task Force on U.S. Nuclear Energy Leadership, *U.S. Nuclear Energy Leadership: Innovation and the Strategic Global Challenge* (Washington, DC: Atlantic Council, 2019), https://www.atlanticcouncil.org/publications/reports/us-nuclear-energy-leadership-innovation-and-the-strategic-global-challenge.

C2ES

Senate Committee on Environment and Public Works Subcommittee on Clean Air and Nuclear Safety

Hearing entitled, "Advanced Nuclear Technology: Protecting U.S. Leadership and Expanding Opportunities for Licensing New Nuclear Energy Technologies" June 4, 2019

Questions for the Record for Mr. Perciasepe

July 1, 2019

Senator Braun:

1. Last month, the Atlantic Council released a report on U.S. nuclear energy leadership which notes that today Russia and China are building more than 60 percent of the globe's new nuclear plants.

a. How do China and Russia view nuclear energy as part of their geopolitical strategy?

The Atlantic Council report notes that Russia and China use nuclear power exports (including plant construction, long-term maintenance and fuel agreements) and financing to increase their political and economic influence in countries. As these facilities will operate for six decades or more, the relationships and deep ties they develop will extend for generations. Moreover, with climate change a rising concern, the market share for zero-emission electricity like nuclear power plants is expected to grow significantly. Therefore, countries with an early lead are in an advantageous position to capture future economic and other benefits.

b. What geopolitical risks are presented to the United States if the U.S. does not remain the leader in civilian use of nuclear energy?

Without competitive, domestic nuclear power plant offerings (reference designs), the United States is missing out on the (commercial) opportunity to export to developing (and other) nations seeking clean, reliable electricity sources to grow their economies. Additionally, the United States is forgoing an opportunity to strengthen ties with allies and to cultivate new relationships with other countries. The United States is more responsible with respect to non-proliferation and safety attributes of its reactor designs than Russia and China. Having the United States as a leading exporter of its reactor technologies reduces proliferation and safety risks globally.

c. In what ways would further development of advanced nuclear technology in the U.S. help us maintain regulatory and technology dominance?

An ideal power plant of the future would be affordable and have flexible on-demand operation, zero-emissions and minimal impact on land-use. New advanced reactor designs can dependably generate zero-emission electricity and useful heat, and they are scalable to produce large quantities of energy from a very small footprint. New designs hold the promise of being even safer and more affordable (domestically and internationally competitive) with the capability of operating more flexibly (as a complementary backstop for variable renewable generation), and they are expected to produce less waste than the current generation of reactors. Certain new designs are intended to make use of the current light water reactor waste stockpile, turning a liability into a valuable national asset.

Regulating new designs will likely require a paradigm shift from business-as-usual. To date, the NRC has only evaluated light water reactor designs. Its current approach is highly prescriptive, viewed by some as lengthy, but has engendered a highly-utilized reactor fleet that is the envy of the world. A flexible and less-prescriptive approach is in use in Canada. Its highly-respected nuclear regulator focuses a constructive, proactive role. It provides clarity with regards to the regulatory process and regulatory requirements and guidance, working with developers (of varied designs) very early in the design process. This approach ensures that regulator and developer are in sync and avoids costly rework and redesign, among other things.

Senator BRAUN. Thank you. Thank you for your testimony.

The committee is scheduled to meet through 1 o'clock, and I intend to keep it open that long, unless we just run out of questions. I don't think that is going to happen. So I would ask fellow members to keep the questions to 5 minutes, so we can keep churning through everyone getting a chance to do a second or third round. And we will have others join as well.

I still start it off by making this general statement. I had the pleasure of seeing a nuclear facility, the Cook Facility, in Michigan. I was overwhelmed by how well it was run, the redundancy with the emphasis on safety. It was harder to get in and out of that facility than I think of any building I have tried to get in and out of here, even once they know you are a Senator. So that was very impressive.

I think what we are talking about here, for any of us that are worried about the climate, and to eliminate carbon emissions, this is the only bird in the hand that I can see that is scalable. There is another thing in economics called sunk costs. We have sunk a ton of costs into nuclear energy. And the fact that we are talking about shutting down plants, some plants having trouble, whether they want to do the extensions that are out there that they can pursue, I think it would be a travesty if we don't find a way to navigate into the future. You can see our geopolitical competitors look at it otherwise.

So for the sake of myself, other members here, and folks out there listening, I want to start off with Mr. Levesque. Advanced nuclear technology, give us a little description of how that is different. Use megawatts in terms of, we heard it is safe, and that it could never create a catastrophe. I think that would be the heartburn that anybody has with nuclear energy. Tell me about that.

Then also tell me about the industry's appetite to scale to into where it would even be more important as a percentage of our electric generation, as opposed to something that we pursue timidly. Contrast that to the plants that are online, and I would also like you to comment, Russia and China, are they building advanced nuclear facilities only? Or are they doing more of what we have come to know as the status quo?

Mr. LEVESQUE. Thank you for your question, Senator Braun. Speaking for the advanced nuclear energy, there are many new advanced nuclear technologies that have appeared over the last 10 years. That is why you have seen many new companies, companies like Mr. Magwood brought up. I would say a major enabler to these advanced nuclear technologies coming into focus is, advanced computer modeling.

We have 98 Generation II reactor plants in the U.S. that have been operating safely for decades. Those are pressurized water reactors, light water reactors as we call them. It is a very safe technology. It is the result of U.S. Government development efforts that go back to the 1950's, when we built plants like Shipping port, and when the nuclear navy made technology decisions.

So these hundred or so plants that are operating today are the result of significant U.S. Government sponsorship that goes back decades, and we are still reaping the benefits of those decisions and that support going all the way back to the 1950's.

So again, those plants have been operating very safely today. If we go back and look at the 1960's and 1970's, there were also U.S. Government efforts to look at non-light water reactor technologies. Examples of those technologies were the molten salt reactor experiment at Oak Ridge National Labs, and the experimental breeder reactor at Idaho National Labs. The EBR, experimental breeder reactor, was a sodium cooled, and given by its name, the molten salt reactor experiment at Oak Ridge was salt cooled.

So even though the U.S. did not decide to pursue those technologies and commercialize them at that time, the U.S. Government did prove that those technologies were viable, and that the basic engines of those plants could be built and operated safely. So the idea of sodium cooled or liquid cooled, liquid salt cooled reactor is nothing new.

But what we have had happen in the last 10 to 15 years is really due to the advent of very high-fidelity computer modeling, where we are obviously, 20 years ago, the computing power simply did not exist to make these designs. That is why we have all this attention now on advanced nuclear. That has a lot to do with the founding of TerraPower. Twelve years ago, Bill Gates and Nathan Myhrvold, and our other founders were together, and they were looking at, hey, how can we create a new source of scalable, clean energy. At this time, they had physicists with them from Lawrence Livermore National Labs, and they said, hey, we think we can go back to these old designs—go ahead, Senator Braun.

Senator BRAUN. To honor the 5-minute rule, we will come back and get the rest of that long set of questions I had.

Mr. LEVESQUE. OK, sure.

Senator BRAUN. I am going to turn it over to Senator Whitehouse now.

Mr. LEVESQUE. OK, thank you.

Senator WHITEHOUSE. Thanks very much. I want to start by reading something from the exhibit to Mr. Magwood's testimony. It asks the question, on page 11, it is the appendix. What should policymakers do? And then it answers the question as follows: implement carbon pricing as the most efficient approach for decarbonizing the electricity supply. This approach would increase the cost of high carbon generation technologies, reduce greenhouse gases and enhance the competitiveness of low carbon technologies, such as nuclear and VRE. Carbon pricing will produce an overall gain for society.

However, it will also produce losses for some stakeholders, in particular, fossil fuel producers and their customers. Appropriate policies to facilitate a "fair transition" for the affected businesses and households, particularly those in vulnerable regions and communities, will be needed. No one can be left behind.

I just want to go on the record as somebody who has a carbon price bill, who is an ardent advocate for a price on carbon, in offering my personal commitment to my colleagues that we will work with them to make sure that standard of no one left behind gets met. We can't be in a situation where the whole U.S. Senate is held hostage in order to take care of people in a way that ignores the coming disaster when, by addressing the coming disaster and reme-

diating and preventing the coming disaster, we can actually take better care of those same people.

I am willing to do all the pensions of everybody who ever swung a pick in a coal mine or drove a piece of equipment in a coal mine, fill them up, a lot of them are broke. Make all those pensions solid, let people retire now, if they want to. Fill up the health and welfare plans, make sure they have health care for themselves and their families for the rest of their lives. I would support a GI bill for the men and women who have worked in our energy sector who are having a transition concern, for them and for their children.

There are ways that we can make this a fair transition. The bill that I have proposed raises $2.3 trillion over 10 years. We can make every miner a king.

Senator CARPER. Or a queen.

Senator WHITEHOUSE. Or a queen, out of those revenues, and still leave plenty to make sure that this is done in a way that helps jet the economy forward the way almost every economist who has looked at this suggests. And I would suggest that the economists who come to a different conclusion, you can trace that back to fossil fuel industry influence.

So I just want to go on record saying that I am eager to make sure that the, what I will call the Magwood standard of no one left behind, but a carbon price being essential, is met.

Mr. Perciasepe says the fooling in his testimony: "Nuclear power has been providing a significant environmental benefit for decades. Society and markets in most instances are not valuing that." Bob, that is what you just said. You go on to say, "Modeling to date clearly shows that we need nuclear power, renewables, carbon capture and improved energy efficiency to achieve large-scale economy-wide emission reductions."

Describe for me what the difference is between no carbon price and an economically effective, robust carbon price with respect to the opportunities for nuclear power, renewables, carbon capture and improved energy efficiency.

Mr. PERCIASEPE. Thank you, Senator. The driving force behind the concept of a carbon tax or a carbon fee or tax incentives that provide those differentials is to use the power of the economy, the market, to drive the change, to drive the movement of private capital into the needed investments. So it is not only on the backs of the Federal Government to do it, but it moves the capital into the technologies that are going to be the technologies of the future.

Senator WHITEHOUSE. So all four of those technologies?

Mr. PERCIASEPE. All four of those technologies, including not only energy efficiency, existing nuclear, more incentives for investment by the private sector and advanced nuclear, because there will be a turnover during this century. The advanced renewable technologies and batteries and electric vehicle technologies and infrastructure, as well as renewable energy, straight-up.

Senator WHITEHOUSE. In the second round, I will pursue that further, specific to carbon capture. But time in this round has expired, so let me yield to Senator Carper.

Senator BRAUN. Mr. Carper.

Senator CARPER. Thanks, Mr. Chairman, and to our ranking member, thank you so much for calling this hearing. I could be in

a number of other places right now, but I wanted to be here. It is good to see you again, Mr. Magwood, thank you for your service in the NRC and the Navy salutes Navy. I spent a lot of years of my life tracking Soviet nuclear submarines from Navy P–3 airplanes. I am very grateful for your service in that regard, and for being here today.

For our neighbor, Bob, it is great to see you again, and thanks for your years of service in so many different roles.

I especially want to thank Sheldon Whitehouse for his terrific leadership on this, and for trying to find common ground on these issues. He and I are joined at the hip in the idea that we can clean-up our air, cleanup our water, try to address climate change, create jobs. I think that is something that ties us all together. For me, that is the holy grail for where I want to go and where we need to go.

Nuclear power serves our Nation's largest source of reliable carbon-free energy, and several of you have alluded to that already, which can help combat the negative impacts of climate change and at the same time, foster economic opportunities for a lot of Americans. If we are smart, we are going to replace our aging nuclear reactors with new technology, hopefully, in this Country, that is safer and produces less spent fuel and is cheaper to build and to operate.

I would ask each of you just to take a moment and share with us one thing, each of you share with us just one thing, that the Federal Government is doing right in this regard, and one area where we could do a better job in order to support the development and deployment of advanced nuclear power. And I would ask Mr. Perciasepe to just lead us off. Again, the question is, share with us one thing with the committee, one thing the Federal Government is doing right and one thing the Federal Government could do a lot better to support the development and deployment of advanced nuclear power. Bob?

Mr. PERCIASEPE. I think getting the proper incentives in place, particularly whether it is carbon pricing or other tax incentives, other forms of tax incentives, those signals are going to drive capital to help invest. So you put that on top of putting the full force of the Federal, intelligent lab facilities behind this, I think would be the best thing the Federal Government could do.

Senator CARPER. OK. Chris?

Mr. LEVESQUE. One thing the government, and specifically this committee, has done very right, I think, is the passage of NEIMA. That really empowers our safety regulator to entertain these advanced reactor designs. So thank you for that support.

One area where improvement is needed, I think, and the committee is already focusing on this, is with NELA, the Nuclear Energy Leadership Act, we really need a demonstration project, we need multiple demonstration projects in the U.S. where we actually design, build and demonstrate advanced technologies. Otherwise, this will all be talk and we won't realize this new technology in the United States.

Senator CARPER. All right, thank you. Mr. Magwood, please, two questions, just briefly.

Mr. MAGWOOD. Thank you, Senator. I think I would agree with what both my colleagues on the panel have said. But I would emphasize that more than anything else, what the government is doing right is just bringing attention to this issue of innovation in advanced nuclear technologies.

This is probably, in the time that I have been in, well, I am not really in Washington at the moment, but since I have been around in Washington, I don't think the interest in advanced nuclear technology has been higher than it is today. I think there is a lot of excitement and enthusiasm, both in the government sector and in the private sector, toward this subject.

But I do think that moving from that excitement to implementation is something we really have to give a lot of focus on. It is going to be difficult, expensive work that I think the government will have to play a large role in. That is, I think, the next step in this conversation.

So I agree with what Chris was just saying, that building demonstration facilities, don't underestimate how difficult this is and how much it will cost. We are really talking about large amounts of money. But that is what is happening in other countries. And if it doesn't happen here, then the opportunities will go overseas.

Senator CARPER. All right, thanks. I don't have time to ask and receive your answers from all of you on this next question. I am just going to just State the question, if I can, and I will ask you to respond to it for the record.

I think there at least six different advanced reactor technologies that could be pursuing a license from the NRC in the near future. The question I will ask you for the record, you don't have to write it down, you will get it from us subsequently, do you believe there are critical skill gaps at the NRC that affect how the agency is able to review and consider applications for the use of technologies? That is one.

The second half of the question that I will submit for the record is, if so, has Congress done enough, has the Administration done enough to address those skill gaps? I would just ask when you get those questions, please respond to us in a timely manner. Thank you so much, and again, my thanks to our chair and ranking member for scheduling this and for all of you joining us. This is a hugely important issue, and we are grateful.

Senator BRAUN. Thank you, Senator Carper. We are going to start another round of 5-minute questions. Chris, I will start, and we will maybe have some other members maybe come in here, we will get with them.

We were at the point of, I want to know about our competition. So what are China and Russia building, what kind of plant technology? Talk about how many megawatts of generation, because that is what I understand here, that is kind of the basic measurement on electric generation.

And then contrast the present capabilities to what you think will be the advanced technology that is going to be scalable, and talk about its features, elaborate a little bit in terms of fuel storage, safety. You hit on a little bit of that, it sounded like, it took a lot of those issues out of place.

So first start with China and Russia, what are they doing? Because they seem to be really energetic with nuclear energy. What kind of plants are they building?

Mr. LEVESQUE. China and Russia are each moving forward with dozens of new bills, both in their own countries and in export markets as well. Most of these gigawatt level plants are Generation II technology, like the 98 plants we have in the U.S. Some are moving to Generation III, which was also largely based on U.S. technology.

They really have their eye, though, on these advanced nuclear technologies. There are several demonstration plants around the world now. People are really looking to these U.S. precedents. The things we did in the 1960's and 1970's combined with what all the advanced reactor companies in the U.S. are now doing with computer modeling and the materials advancements.

Senator BRAUN. You mentioned computer modeling as a difference. Give me some other differences, so I can easily understand what Generation I and II is, and then what this miracle might be, if we ever see it.

Mr. LEVESQUE. So this is leading to some of the benefits of advanced reactors, and this applies to many of the technologies. These are now low-pressure systems. They are systems that have inherent safety, meaning we don't need a lot of extra mechanical and electrical systems.

Senator BRAUN. Can you store fuel onsite when it is spent?

Mr. LEVESQUE. They do require onsite fuel storage, and some of them require a future geological repository, which the U.S. Government is working on. But many of these technologies, like TerraPower's, also because of the computer modeling, they add very advanced physics to the core that generate much lower waste at the end of the fuel cycle, up to an 80 percent reduction in that waste.

That is why China and Russia, even though they are building plants that are much like what we developed in the U.S. They have their eyes on these advanced reactor designs, and really, the U.S., because of our national lab complex, and our legacy from those plants I mentioned——

Senator BRAUN. But not developed yet, still in developmental stage?

Mr. LEVESQUE. Right. But we are really the best poised, the U.S. has a leadership opportunity here that, if we don't take it, China and Russia will. But we are best situated today to take leadership on advanced reactors. If we don't, China and Russia will in a very short period of time. The time to act is now, as in this year. We need to begin work on demonstration of advanced reactors.

The Generation II facilities, what are the megawatts of generation capability? Roughly, on the larger ones.

Mr. LEVESQUE. Generation II facilities, we usually refer to as gigawatt level, 1,000 megawatts electric on each plant. Sometimes slightly larger or smaller. Each enough to power 1 million homes.

Senator BRAUN. What would the forecast be on the advanced technology approach? It is less, isn't it?

Mr. LEVESQUE. Some. Because TerraPower wants to attack the huge increase in global electricity demand and fight climate change, our company is going after these same gigawatt level

plants. In certain niche areas, we can build smaller plants. But I would say advanced nuclear offers the flexibility for anything from a microreactor to gigawatt scale. Advanced reactors doesn't necessarily mean you go big or small.

Senator BRAUN. It will be a complete difference in technology that has flexibility and much better safety features.

Mr. LEVESQUE. Absolutely. It will have inherent safety, it will be a lower pressure system, it should have a much smaller emergency planning zone. And then another major, major benefit is, these advanced reactors will run at higher temperatures, which will make them more efficient and also more able to supply industrial processes.

Senator BRAUN. Thank you. Senator Whitehouse.

Senator WHITEHOUSE. Thanks, Chairman.

Just to confirm something that I think is probably the case, from the testimony and from the body language from my last question, do each of you support a price on carbon? Director Magwood.

Mr. MAGWOOD. As I mentioned in my oral remarks, and in the written statement, our view is that the markets need to be reformed and restructured entirely. Depending on what the objectives of the particular country that is reforming its markets have in mind, you can shape those markets to accomplish those markets what you want. You mentioned economists. This particular view of our economists, there is no better way, if your objective is to reduce CO2 emissions, there is no better way than introducing a cost on carbon.

Senator WHITEHOUSE. And there are ways to do it fairly, that you would want to do?

Mr. MAGWOOD. Yes.

Mr. LEVESQUE. We think a broad range of incentives are needed, beginning with serious government R&D investment, but also including carbon incentives.

Senator WHITEHOUSE. Including a price on carbon, of some kind.

Mr. LEVESQUE. Correct.

Mr. PERCIASEPE. Yes, is the simple answer. It will stimulate all the different technologies we need, from carbon capture on fossil sources to——

Senator WHITEHOUSE. We ended with carbon capture. Let me focus specifically on that. With respect to carbon capture, in a world with a carbon price and a world without a carbon price, what is the difference for a carbon capture innovator with regard to what they are looking at as a revenue proposition?

Mr. PERCIASEPE. Say that again.

Senator WHITEHOUSE. You have two identical worlds. You have the same innovator; you have the same carbon capture technology. In one world, there is a carbon price and, in another world, there is not. What does that mean for that innovator to have or not have a carbon price with respect to their prospects for having a revenue proposition? If it is free to emit carbon——

Mr. PERCIASEPE. Right. That is generally currently free, to emit carbon, with some nuances, like what they use in California. But what to do with the carbon when you capture it, there is a cost of capturing it. Although those technologies are evolving quickly, I want to——

Senator WHITEHOUSE. The point I am trying to ask you about is, whether it helps this, in carbon capture innovation, if you have a carbon price. Because the existence of the carbon price gives an incentive for people to pay for that innovation, which gives the innovator a revenue proposition for their business plan. Otherwise, you are standing next to the smokestack with the carbon going up into the air for free, and you are saying, who is going to pay me to take that out of the air, when it is free to pollute? Why would that make any sense?

Mr. PERCIASEPE. Whatever you are going to do with the carbon, if you are, if there is a financial incentive to capture it and do something with it, you are going to do it. And that is going to stimulate those carbon capture technologies to go even faster and innovate and become cheaper.

Senator WHITEHOUSE. Totally a real success on.

Mr. PERCIASEPE. Yes, and it has had, as you know, bipartisan support.

Senator WHITEHOUSE. Yes, with our chairman on this committee, on the full committee.

Mr. Levesque, one of my earliest exposure to TerraPower involved a proposition that the technology had the promise of allowing us to go back through the currently just sitting there nuclear waste stockpiles that we have, for which we no plan, and actually be able to utilize that and repurpose it as fuel, and turn, as I said in my opening remarks, a liability into an asset.

Is that still a focus of TerraPower? Will it remain a focus of TerraPower? Is it a focus of the industry? What can we do to help make sure it remains a focus of the next gen, or Gen IV industry?

Mr. LEVESQUE. Senator, you point to a very major capability of advanced reactors. Today's reactors only use about 5 percent of the fissile material before the reactor has to be shut down and the fuel is removed. It is just the way the physics work. The advanced reactors, including TerraPower's design, much more completely use that fuel.

Now, TerraPower's designs today plan on using depleted uranium, which is the waste product of the enrichment process. We can use either depleted uranium or natural uranium to fuel the traveling wave reactor.

However, this entire new family of advanced reactors does offer the potential to go and look at spent fuel. Of course, we are waiting for the U.S. to develop a geologic repository for spent fuel. But advanced nuclear technologies do allow you the opportunity to go look at what amount of fissile material is remaining in that spent fuel, and is there a way to utilize more of it. So that is yet another benefit of advanced reactors.

Senator WHITEHOUSE. If I may make a comment, Mr. Chairman.

Senator BRAUN. You may.

Senator WHITEHOUSE. I know that you come from a very strong business background. If we were running United States, Incorporated, the liability of all that nuclear waste we have stockpiled all around the Country in dozens of sites would show up when your auditors came. And when you did your financial reporting to your shareholders, they would say, here on the debit side of the column is this liability that you have for having to deal with this nuclear

waste at some point. And if it was a $500 million liability, you would have an incentive to spend up to $499 million to clean it up.

But because we are the United States of America, not the United States, Incorporated, there is no place where it shows up in our balance sheet. So we really don't have that persistent economic incentive that a corporation would have to deal with it as a national issue.

There is a bit of a carbon price flavor to the point I am trying to make, but this is like the reverse of it. There is this liability, and there is no way in which, as I can see it, that a TerraPower or somebody else can say, OK, there is a $500 million problem, that means I can come up with a $200 million solution and then we can split the difference, and I will make $150 million and my business sense gets motivated, my innovation juices start to flow, to solve that problem. Instead, it just sits there, and the stuff has sat there for decades, and we are waiting for the magic solution to go put it into Yucca Mountain or some place. But I don't see that happening without a revolt from Nevada.

So we need, I think there is an economic solution here as well. If this was a pure business proposition, there would be a lot more energy in solving it. Because there would be this account that was dragging on our balance sheet saying, fix me, fix me, fix me.

Senator BRAUN. Now that there are basically two of us left, we are going to go, I think, back and forth with the dialog like this. I think that is healthy. So I am going to jump in as a business guy.

You would never—you have a contingent liability, one that might occur, this is a liability sitting on the pads. It was there at Cook nuclear facility. And how we are going to resolve that, I don't know. That discussion has been going on for a lot longer than the short time I have been here. That still is going to be an issue regardless of what happens with advanced technologies.

So I think that whether you price carbon, what you do with that liability that is a real one, both are issues that cloud what is going to happen with nuclear energy. The thing that I have heard that I like most is that there is new technology that is going to address all the inherent disadvantage of nuclear. You have processes now that you are able to use technology to run them better. You mentioned that. Safety is less of a concern, because it is not inherently risky, like the old process.

It begs the question for me, because I think that is valid. We have to address it.

How much of the current cost per kilowatt is built in with safety and regulations currently that, now that we know so much more now than what we used to know, how much does TerraPower or any other business utility that generates electricity through a nuclear source, how much per kilowatt is that costing? Does that put you inherently less competitive than, say, for instance, now, natural gas, which is adding to our carbon footprint? Can you tell us roughly what that amounts to?

Mr. LEVESQUE. I would say that I think many of those savings that you are talking about have been realized in the last 20 years with our operating plants that have worked on power operates, they worked on regulatory reform. As a result, what you have seen is the dollars per megawatt hours for the plants in the U.S. have

decreased from something like 40 plus dollars per megawatt hour down to the low 30's.

So I think many of these benefits have now been realized. There is probably not much more potential there to go and get savings. I would say the big opportunity, or the mandate now, is to move to new technology. There is new technology available that we have to go get.

Senator BRAUN. What has been forecast to be? How much additional savings per megawatt hour? Is that part of the equation?

Mr. LEVESQUE. Absolutely. In general, we believe those reactors should be at least 20 percent cheaper than existing reactors on operating costs. That is going to vary.

Senator BRAUN. Taking it down about four bucks per megawatt. Where is natural gas in the other stuff down there?

Mr. LEVESQUE. Natural gas today is making it very hard for any nuclear power plant to compete at a profit, unless it is——

Senator BRAUN. Unless you are taking it all around carbon.

Mr. LEVESQUE. Right.

Senator BRAUN. Because it is emitting it. So defer to that line of question, with all that you need to know in terms of certainty and running any business, do you think, now, you are in a market, and obviously the least expensive, cleanest fuel will run in the long run. Do you think that with what it would take to invest in even advanced technologies that you would do that as a company, with natural gas out there, being at a lot less megawatt hour?

Mr. LEVESQUE. Yes, absolutely we would. We believe the U.S. Government should think strategically about its energy supply and natural gas is cheap today. But we need to think decades ahead. We think that you absolutely need nuclear and advanced nuclear in the mix. We think the economic potential of advanced reactors should make nuclear energy even more affordable. And some of those technology enablers I mentioned to you, having lower pressure systems, having less mechanical and electrical systems because they are inherently safe, there is all of these technology enablers that should make advanced reactors cheaper than today's plants.

We are just really at a time when we have extracted most of the savings that we can get out of the current technology. It is time to move to a new technology that is available. And it is a new technology that the U.S. is, because of our national labs, because of the work we did in the 1960's and 1970's that we kind of set aside, the U.S. is really the most well-positioned country in the world to be the leader in advanced nuclear.

Mr. PERCIASEPE. Just to add to this business balance, most of the industry that works in the natural gas arena has it on their mind and in their future planning that there will be more cost to them to capture the carbon that comes out of those generators. Also of tightening up their system, so methane isn't leaking out into the air. So right now, that is not priced into the price that is going to me in my house.

But most of the companies thinking of the future, just like the liability issue we were talking about, can advanced reactors be part of the solution to spent fuel, most of the companies looking ahead at their prices, not so much of getting the gas, like has become so

efficient with directional drilling and hydraulic fracturing, but the other issues that they are not currently having to have an expense on.

So I think that there is where you have to look at, where is that business going to be in the future and how they will match up with each other, and what incentives the Federal Government should be putting in place to make sure they all get to the right place, so the consumers are advantaged.

Mr. LEVESQUE. If I might add, Senator, we look at the nuclear industry, we are thinking globally. Natural gas is not available at the low cost and at the volumes that we enjoy in the U.S. So we are talking about developing advanced reactors in the U.S., we are talking about demonstrations of advanced nuclear technology that we can prove out in the U.S. and then deploy to many other countries that have growing energy demand, and that have higher prices on natural gas.

So we can be very competitive overseas. There will be tremendous demand for electricity and industrial heat overseas, and advanced nuclear will compete very, very favorably with fossil sources.

Senator BRAUN. I am going to followup with one more question and then let Senator Whitehouse ask the final round here. Do you think we can survive, due to the fact that natural gas and other competing fuels have higher costs per megawatt hour? Can the U.S. industry, since it is a different technology that can be exported along the lines of what you are talking about? I know that is not ideal, but do you think that is a way we can hang in the game while we are trying to get through all the issues that currently beset the U.S. nuclear industry? Mr. Magwood?

Mr. MAGWOOD. Senator, I think that as we look through our analysis on where nuclear competes and where nuclear doesn't compete, the single effect that seems to overwhelm everything else is actually the cost of building a nuclear power plant. There is no other factor that seems to be affecting nuclear in most markets. You can talk about safety, you can talk about waste, you can talk about a lot of these other things. But the actual cost of building a plan has become a huge barrier, both for current generation and I think is going to be a barrier for future generations.

So I think one of the things we have highlighted is that there has to be a more cost-effective way to build nuclear power plants. I think that the days of expecting ratepayers and taxpayers to support facilities that cost ten plus billion dollars, those days may very well be over. When I talk to utility CEOs, they tell me they don't see big plants being built any more. They are emphasizing small plants.

I think the reason they emphasize the small plants is, this doesn't quite fit the TerraPower framework, but I think there is a desire to move away from the traditional approach of building plants and move to a manufacturing approach, to where nuclear power plants look more like jet airliners. We know how to do that. The 787s come off the assembly line by the hundreds. It is cost-effective to get an economy scale from that. That is where I think industry, in large part, would like to move toward.

If you can do that, become more cost-effective, I think there is a chance for nuclear to compete in a broader range of markets. As it is right now, it just simply costs too much. I will relate what I heard from a minister of an eastern European country, who told me that it doesn't really matter how good the technology is, if I can't afford to build it.

Senator BRAUN. Senator Whitehouse.

Senator WHITEHOUSE. Thanks, Chairman.

Director Magwood, in my opening comments I mentioned the NRC's behavior around what they called the mitigation of beyond-design basis events rule to address earthquake, flood, things like that. As I recall, you were a commissioner when this was first brought up.

It seems peculiar to Ranking Member Carper and myself, as our letter reflects, that without any comments in the regulatory process supporting these rules being merely voluntary, and without a staff recommendation that the rules should be voluntary, without testimony that the rules should be voluntary, it seems like there was full agreement, everybody on course, for the rule to be a mandatory rule, which also makes sense, to me, anyway, when you are considering the risks involved.

So it came as kind of a stunning surprise that there was a partisan opinion that emerged out of the NRC on this issue, and it is particularly disturbing to me when you are seeing this happen on a topic where we have managed to achieve bipartisanship here in the EPW committee and here in the Senate. I mean, for Pete's sake, if there's any body that is supposed to be partisan, it is us, not a bunch of nuclear regulatory commissioners.

So when we can solve our problems and make progress with these two nuclear innovation bills and get them passed, and then we see the commission divided along partisan lines and doing something that, to me, from a regulatory process point of view, makes no sense, it just seems odd. I wonder if you, I know you weren't there when it ended, but you were there when it began. Does your experience as a commissioner give you any insight into what we should be looking for or what was up with that?

Mr. MAGWOOD. Let me share this thought. And I am aware of the discussion about the mitigating strategies rule, as you mentioned. A lot of this got started when I was on the commission. I think it is important to emphasize that the orders that were issued by the NRC in the years after the accident in Japan put in place a framework of safety to make sure that plants had been brought up the standards the commission saw as necessary to protect safety across the Country. So I don't think that there is a safety issue at play as we stand today.

The process with rules is such that, and I can tell you, there were certainly cases where the staff made recommendations to the commission and some commissioners just simply didn't agree. That is what commissioners are there for. That is why they go through the process of confirmation, because you are looking for their expertise and their judgment. Sometimes we don't agree with the staff.

I can tell you there are cases where, in the post-Fukushima environment, I will give you a very specific example that left a lot of hard feelings with people, and that was the discussion about

whether we should require filtered venting on Mark II reactors. This was a big debate on the commission. The staff recommended it, three commissioners just didn't believe it was necessary, two did. And it was a big debate about that.

When I was on the commission, we just did not look at this in a partisan way. Sometimes it came out that way, and I think regulatory philosophy reflects that. But in large respect, the discussions that I have had on the commission never really broke down along those lines. It is unfortunate that this particular issue seems to have gotten that kind of play in the press.

But my view is that there is an honest debate that takes place on a commission. There is voting that takes place. And if three commissioners agree, that is the direction it goes. Whether it is three commissioners who are Republicans or three commissioners who are Democrats, that is the way the process works. I think that is a healthy process, because that debate, often you learn things from even the colleagues you disagree with that ends up in the final package.

So I know the commissioners, I think they are all people who are trying to do the right thing. I have met all of them and I have talked with all of them. We don't often agree on things, that is part of the process. But I think they are all people who care about safety and are trying to do what is best for the American people.

Senator WHITEHOUSE. OK. Thank you for sharing that.

Mr. Chairman, I have nothing further. Thank you for this hearing.

Senator BRAUN. Thank you for testifying. It was a good, robust conversation, and I think we all want to make sure what we have invested in nuclear energy up to this point is not lost. We don't want our world competitors to outpace us at this moment in time. We do want to decarbonize electric generation.

So hopefully we will have more discussions like it, and thank you again for coming. Any member that would want to add to it can submit followup questions for the record. The record will be open for 2 weeks.

Thanks again for coming. This hearing is adjourned.

[Whereupon at 12:50 p.m., the hearing was adjourned.]