Developing and Deploying Advanced Nuclear Energy Technologies

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Introduction

Thank you, Chairwoman Shelley Moore Capito and Ranking Member Sheldon Whitehouse, and members of the Subcommittee, for this opportunity to speak to you today. I am Dr. Kemal Pasamehmetoglu, Associate Laboratory Director for Nuclear Science and Technology at the U.S. Department of Energy's (DOE) Idaho National Laboratory (INL). I am honored to participate in this distinguished panel before the Subcommittee. I request that my written testimony be made part of the record.

Before I begin my testimony, I would like to thank Senator Capito and Senator Whitehouse for continued support of research and development efforts conducted by the national laboratories and strategic partners in support of advanced nuclear technologies. Your co-sponsorships of the Nuclear Energy Innovation and Modernization Act, S. 2795, is an essential bipartisan enabler to nuclear innovation. Senator Whitehouse's sponsorship and authorship of the Nuclear Energy Innovation Capabilities Act, S. 2461, along with Senator Crapo from my State of Idaho, and New Jersey Senator Booker, also demonstrates the bipartisan interest in the future of advanced nuclear energy technologies.

The Value Proposition for Advanced Nuclear Energy Technologies

Recognizing reliable, secure, and affordable energy as the engine for economic growth, prosperity, and quality of life, there is considerable global and domestic interest in advanced nuclear energy systems. A recent International Energy Agency study that explores options to limit global warming to 2ºC projects a global demand for nuclear energy at approximately 960 GWe, compared to 370 GWe today. The advanced versions of the large light-water reactors currently in use will likely partly contribute to this expansion. Small modular reactors (SMRs) cooled by water and other advanced reactors that are not cooled by water are also expected to penetrate this market in the next few decades starting in the early-to-mid 2020s.

In the U.S., the current light-water reactor fleet has been the workhorse of emission-free baseload electricity generation at approximately 100 GWe capacity. Nuclear energy currently provides approximately 19 percent of total electricity and 63 percent of our national electricity sector's carbon-free generation today without emitting air pollutants during operations. Nuclear energy's contribution to our national electricity generation and air quality must be maintained and, with advanced nuclear technologies on the near-term horizon, grow into the future.

Predicting the exact future energy mix nationally or internationally is impossible. The policy choices and market conditions will shape the energy landscape. However, it is clear that nuclear energy will likely play an important role as it has many of the attributes necessary for the 21st century energy needs.

Opportunities

The value proposition for nuclear energy is strong. The energy landscape offers the following opportunities for a strengthened U.S. role in nuclear energy technology innovation:

- *Export and Domestic Markets.* The demand for affordable, reliable, clean, safe and secure energy is increasing globally and domestically, and nuclear energy is expected to be a strong part of this energy portfolio. The projected nuclear energy market over the next three decades is more than $2 trillion.
- *Demand for Improved Performance.* There are a number of advanced reactor and component technologies that can meet the 21st century demands in terms of improved economics, security and passive safety, and reduced environmental impact and waste generation.
- *Demand for Reliable Energy.* Reliability is a key attribute for the 21st century energy supply, especially when distributed sources are used. Advanced nuclear energy systems are designed to meet this requirement.
- *Importance of Energy Security.* A diverse energy portfolio and deploying energy sources with predictable prices are critical attributes of the energy policy in terms of long-term national and energy security.
- *Demand for Contributions Beyond Electricity.* Within the framework integrated energy systems, nuclear energy's contribution to energy demands, especially in industrial uses through process heat supply, is being explored both domestically and internationally.
- *Requirements for Emission-Free Energy Production.* The ability to support economic growth while reducing emissions and air pollutants is critical for the future energy scenarios.
- *Importance of International Safety and Security Standards.* To improve the national security posture, the U.S. should exert leadership in safety and security standards while meeting growing global demand for nuclear energy. This can be possible only if the U.S. maintains its technological and industrial leadership, which is currently eroding.

- *Sustaining Intellectual Capacity*. Development of the next generation of scientists, engineers, and technologists who will ensure both economic and national security is key for this critical technology.

From a national perspective, the U.S. cannot rely or securely and affordably meet increasing energy demand with just renewable energy and/or intermittent electricity generation alone or paired with energy storage systems without baseload power. In this effort, nuclear energy, renewables and other clean fuel sources become complementary in nuclear-hybrid energy systems that support multiple applications, including electricity generation.

Challenges

Through a comprehensive energy policy and implementation strategy, the following challenges must be addressed for the U.S. to take advantage of the aforementioned opportunities:

- *Public Perception.* An evidence-based communications campaign is needed to communicate the relative risks and benefits of nuclear energy. While no concentrated energy source that can meet the demand of the 21st century is risk-free, the outstanding safety record and extensive contributions of nuclear technologies to our quality of life should be explained in compelling ways.
- *Energy Economics.* Through advanced designs, manufacturing technologies, and reliance on advanced technologies for operations, the cost of energy production by nuclear must be competitive with other energy sources while crediting the supply reliability and emission reductions through policy adjustments.
- *Distributed Energy System Integration.* 21st century energy systems and electricity grid are expected to rely on more distributed energy sources compared to today's large, centralized power plants. Novel designs, such as those in the form of SMRs, are needed to optimize the use of nuclear energy within the 21st century energy infrastructure.
- *Safety.* It is important to deploy systems that rely on inherent safety systems instead of active systems that are expensive and require a highly trained workforce and mature safety infrastructure. Compared to similar concentrated energy sources, nuclear energy has a stellar safety record in the U.S. and places like France with high reliance on nuclear energy. Increased reliance on inherent safety systems is particularly important for export markets, especially in newcomer countries.
- *Safeguards and Security.* With large-scale global deployment, systems may require enhanced safeguards. Influence on international safeguards and security policies and the development of advanced safeguards technologies are important for export markets. The U.S. influence in this area will be possible to the extent that we maintain our technological and industrial leadership.

- *Waste Management.* A sustainable approach to used nuclear fuel is needed for the long-term use of nuclear energy. The challenge is more political than technical. On the technical side, using advanced reactor systems that favor reduced waste generation and improved resource utilization must be considered. Such systems must address the entire fuel cycle as part of their design, development, and deployment.
- *Technology Development Cost and Schedule.* Time to market for nuclear technology is too long for private investors. The capital cost is also a barrier relative to the cost of other energy technologies. Similarly, the facilities needed to conduct the necessary RD&D activities are very expensive to develop and maintain. The capabilities (e.g., facilities, expertise, materials, and data) are mostly at government sites and have not been easily accessible by the private entities trying to commercialize innovative systems and components. For different advanced technologies, technology readiness levels vary – requiring differing, flexible, and effective public private partnership models.
- *Regulatory Process for Advanced Reactors.* The current regulatory process in the U.S., which establishes a gold standard globally, is primarily tailored for large light-water reactors. A risk-based regulatory framework, which is investment friendly through a phased approach to regulatory risk reduction, must be developed and implemented for advanced systems.

Mission

The joint mission of the nuclear energy enterprise (DOE, industry including vendors and utilities, and the Nuclear Regulatory Commission [NRC]) must be to establish a nuclear energy research, development, demonstration, and deployment (RDD&D) strategy to achieve the following three strategic goals simultaneously:

- Maintaining the U.S. technology leadership
- Re-establishing the U.S. industrial leadership
- Enabling the optimized use of nuclear energy for domestic markets.

Maintaining technology leadership is a necessary but insufficient prerequisite for the U.S. to meet the other two strategic goals. However, due to the sense of urgency in the mission, a sequential approach would not work. Investment decisions must be optimized and phased to meet all three goals simultaneously, while assuring that the future advances subsequent to initial deployment are also supported.

It is also important to note that maintaining the existing fleet for as long as possible is a critical element of the optimized use of nuclear energy for domestic markets.

Vision

In my opinion, a bold but achievable nuclear energy RDD&D vision by mid-century should include the following:

- Maintaining a large fraction of a multi-trillion dollar world market share for the U.S. industry sector, which includes deployment of new plants and associated supply-chain and support services.
- Providing more than 10% of total domestic energy consumption through a combination of existing plants, light-water based SMRs and advanced reactors (GEN IV).
- Implementing an optimized, integrated used nuclear fuel management strategy that is sustainable for the remainder of the century, including the mix of nuclear energy technologies that would be deployed in the future.

Nuclear Energy Technologies: The Paths Forward

Maintaining the existing fleet with approximately 100 GWe capacity for as long as possible until 2030 and beyond is important. In addition, light-water SMRs and advanced reactors provide the opportunity to re-establish the domestic nuclear industry (entire value chain) – a key to global leadership. The U.S. has the opportunity to regain domestic manufacturing and supply chain capabilities that were lost by not building new reactors during the last 30 years. My testimony includes the status, maturity, and applications of nuclear energy technologies on the horizon.

Small Modular Reactors

DOE has worked to establish effective public-private partnership models dedicated to accelerating commercial readiness of innovative technologies in order to enable industry leadership and domestic deployment. Beyond GW-scale light water reactors, light-water cooled SMRs are the most mature advanced reactor technology, with the NRC currently reviewing NuScale Power's design certification application.

The NuScale-designed SMR is an advanced light-water reactor wherein each individual power module is a self-contained unit that operates independently within a multi-module configuration. Each module has an electrical capacity of 50 MWe, and up to 12 modules are monitored and operated from a single control room.

SMRs offer several advantages due to integrated design features. Benefits include inherent safety features, factory manufactured modules, total power sized to demand and increased with increasing demand, and lower initial capital cost by starting with a limited number of modules.

Through DOE, INL is partnering with NuScale to explore the possibility of a MW-scale demonstration of a nuclear hybrid energy concept to include ties to a micro-grid. INL is working with Oak Ridge National Laboratory and the federal Tennessee Valley Authority to research emergency microgrid capabilities and specifically determine whether an SMR could power critical infrastructure after a serious natural disaster or attack.

A nuclear hybrid energy systems concept could be explored through the Joint Use Module Plant (JUMP) initiative, which is a joint proposal by INL, NuScale Power, and Utah Associated Municipal Power Systems, a consortium of 45 western U.S. community-owned utilities. The initiative would allow INL to conduct research that could make NuScale's light-water reactor more marketable on an international stage while paving the way for other hybrid energy reactors. The nuclear hybrid energy concept provides the opportunity to explore additional potential energy applications, including hydrogen production, water desalination, synthetic fuel creation, and other industrial process heat uses.

A revitalized nuclear industry brings with it family- and community-sustaining economic development. The proposed NuScale-designed SMR, which recently received a DOE site use permit for activities at the INL site in southeastern Idaho, will create thousands of jobs during the construction phase and hundreds of permanent jobs with annual incomes far above the regional, state, and national averages. According to an Idaho Department of Labor study, this project would infuse millions of dollars annually into the local and state economies. This is merely one example of how nuclear technology innovation supports economic opportunity and why the U.S. cannot afford to fall behind and lose a competitive advantage to other nations.

The current timeline calls for a first-of-a-kind deployment of the NuScale light-water SMR by 2025. NuScale submitted its license application to NRC in January 2017, and NRC formally accepted the license application in March 2017. This timeline was made possible by the Department of Energy awarding competitive matching funds worth up to $217 million to NuScale Power over five years to develop its SMR system.

Advanced Non-Light-Water Reactor Technologies

Light-water reactors have achieved unparalleled safety and environmental milestones. However, in light of growing demand for clean energy nationally and globally, there is an urgent need to develop and deploy significant new and flexible nuclear energy capacity, starting now and ramping up significantly in the 2030–2040 timeframe.

The next generation of reactors will provide enhanced passive safety features, while increasing efficiency, expanding applications and reducing environmental impact. They will need to be economical and reduce proliferation risk. These aspects require accelerated innovation in order to achieve commercialization of SMRs and advanced reactors in a timely manner.

Advanced reactor designs include high temperature gas reactors cooled by helium gas or molten salt; liquid metal reactors cooled by sodium, lead or lead-bismuth eutectic; and reactor technologies that feature liquid fuel dissolved in fissile and fertile materials with molten salt coolant.

Advanced reactor technologies offer key performance features such as:

- *Higher outlet temperatures* to produce electricity more efficiently and to replace fossil-fuel-generated heat for some industrial applications like chemical production, hydrogen production and water desalination.
- *Enhanced inherent safety systems* to shut down the reactor and remove decay heat effectively even in the event of a full station blackout, such as occurred at Fukushima, and to allow the plant to withstand any conceivable accident scenario.
- *Advanced fuels in various forms* (liquid, particle, metallic, or ceramic) and new cladding materials to operate at higher temperatures, extract more energy from the fuel, tolerate a wider range of operating conditions and reduce waste generation.
- *Advanced power conversion systems* using gas turbines or supercritical fluids to reduce water usage and increase efficiency.

U.S. advanced nuclear technologies need to be available for commercial deployment by 2030 if the U.S. is to obtain a substantial share of the global market for these technologies.

Gateway for Accelerated Innovation in Nuclear

Recognizing the need for accelerated innovation for advanced reactors, DOE's Office of Nuclear Energy established the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative to provide the nuclear community with the technical and regulatory support necessary to move innovative nuclear energy technologies toward commercialization. Through GAIN, DOE is making its state-of-the-art and continuously improving research, development, and deployment infrastructure and expertise available to stakeholders to achieve faster and cost-effective advances toward commercialization of innovative nuclear energy technologies. INL leads the GAIN initiative, which is a multi-laboratory effort.

GAIN is predicated on building strategic partnerships with federal agencies, developers and suppliers, and utilities and other potential end-users for advanced reactor systems.

GAIN has fostered industrial leadership by providing focused research opportunities and dedicated engagement while ensuring that DOE-sponsored activities are impactful to stakeholders working to realize the full potential of nuclear energy technologies.

GAIN serves the advanced nuclear technology developer community in several ways, including:

- Offering a centralized information and communications portal for advanced nuclear technology resources.
- Conducting needs assessments and research-oriented workshops.
- Connecting nuclear energy innovators with national laboratory scientists developing new computational and experimental tools.
- Providing a venue for DOE, in close coordination with the NRC, to work with nuclear technology developers on licensing support.
- Offering training opportunities to the nuclear community.
- Providing advanced nuclear technology developers access to technical, regulatory, and financial support via the broad range of DOE funding options. For instance, GAIN offers nuclear energy vouchers to businesses to accelerate the innovation and application of advanced nuclear technologies. The variety of GAIN voucher applications in 2017 indicates the strong interest in a diversity of advanced reactor technology designs and approaches.

DOE's Lead Laboratory for Nuclear Energy: Idaho National Laboratory

INL is the lead nuclear energy laboratory for the nation and functions as an applied research and development laboratory. For more than 60 years, INL has played an important leadership role in the development and deployment of nuclear energy and, more recently, the development of next generation nuclear reactor technologies.

INL works to enable innovation to ensure that secure and reliable advanced nuclear energy technologies are available to the U.S. and a global energy market. The laboratory is working with federal agencies (including the U.S. NRC), universities, our fellow national laboratories, and nuclear technology developers to establish and maintain a domestic nuclear energy capability. This work is anticipated to culminate in the U.S. providing global leadership and re-establishing a supply chain for advanced nuclear energy systems development and deployment.

INL is in a prime position to take on national challenges and seize opportunities in supporting nuclear energy. INL researchers work to develop technology solutions to ensure secure and resilient energy infrastructure, to enable nuclear material security, to provide carbon-free and pollutant-free baseload electricity and to sustain U.S. leadership in a competitive environment.

INL has formed strategic, advanced reactor partnerships with other national laboratories, selected universities, and the private sector to provide the scientific and technical foundation for innovation in nuclear energy. Currently, INL is working on (1) advanced reactor design evaluation; (2) hybrid nuclear energy systems development; (3) digital instrumentation and control, and human factors research; (4) innovative fuels and materials design development, fabrication, and demonstration; (5) fuel cycle technologies; and (6) modern risk analysis techniques.

INL has unique capabilities and initiatives to support nuclear energy innovation. The capabilities include experimental facilities, multi-scale modeling tools focused on nuclear energy design and analyses, and specialized expertise.

- Unique facilities to provide industry, international, commercial and university partners with access to best-in-the-world capabilities. Facilities include:
    - *Materials and Fuels Complex* – The Materials and Fuels Complex hosts an extensive array of nuclear and radiological facilities for nuclear fuels and materials fabrication, examination and handling facilities. Fuel cycle research facilities also are located at the materials and fuels complex.
    - *Advanced Test Reactor Complex* – Hosting the world's premier nuclear test reactor, the Advanced Test Reactor Complex also features the Advanced Test Reactor-Critical Facility, the Test Train Assembly Facility, Radiation Measurements Laboratory, Radiochemistry Laboratory, and the Safety and Tritium Applied Research Facility.
    - *Transient Reactor Test Facility (TREAT)* – TREAT was specifically built at the INL site to conduct transient reactor tests where the test material is subjected to neutron pulses that can simulate conditions ranging from mild upsets to severe reactor accidents. The reactor was constructed to test fast reactor fuels, but has also been used for light-water reactor fuels testing as well as other special purpose fuels (i.e., space reactors). INL is on schedule to resume operations at this important test facility by 2018.
    - *Research and Education Campus* – The landscape of INL's Idaho Falls based campus has evolved markedly in the past 10 years with several new facilities. The Energy Innovation Laboratory is the gateway to INL's Idaho Falls campus. Other important capabilities include the INL Research Center, the Center for Advanced Energy Studies, National and Homeland Security office and engineering facilities, and the Energy Systems Laboratory.

- Through DOE investments in the last decade, the nuclear energy research and development infrastructure is considerably improved at INL and the rest of the complex. INL also is leading the effort for identifying and establishing new capabilities that are currently missing to support further innovation and future development consistent with the needs of the private sector development activities.
    - A missing and needed capability is a versatile fast neutron source to develop new fuels and materials necessary in advancing nuclear power. INL is currently leading a national study to identify the needs, define the design envelope, and assess the feasibility of a fast spectrum neutron source development in the U.S.
- INL is leading the research for developing a sustainable fuel cycle and waste management system adapted to advanced reactor systems, recognizing that advanced reactor systems offer more favorable fuel cycles.
- The INL-led GAIN initiative provides nuclear innovators and investors with a single point of easy access to the broad range of capabilities (people, facilities, computer codes, materials, and data) across the DOE national laboratory complex.
- The Nuclear Science User Facilities (NSUF) merges the national nuclear research infrastructure with university and industry research to offer new capabilities and new opportunities to nuclear energy innovators.

Summary

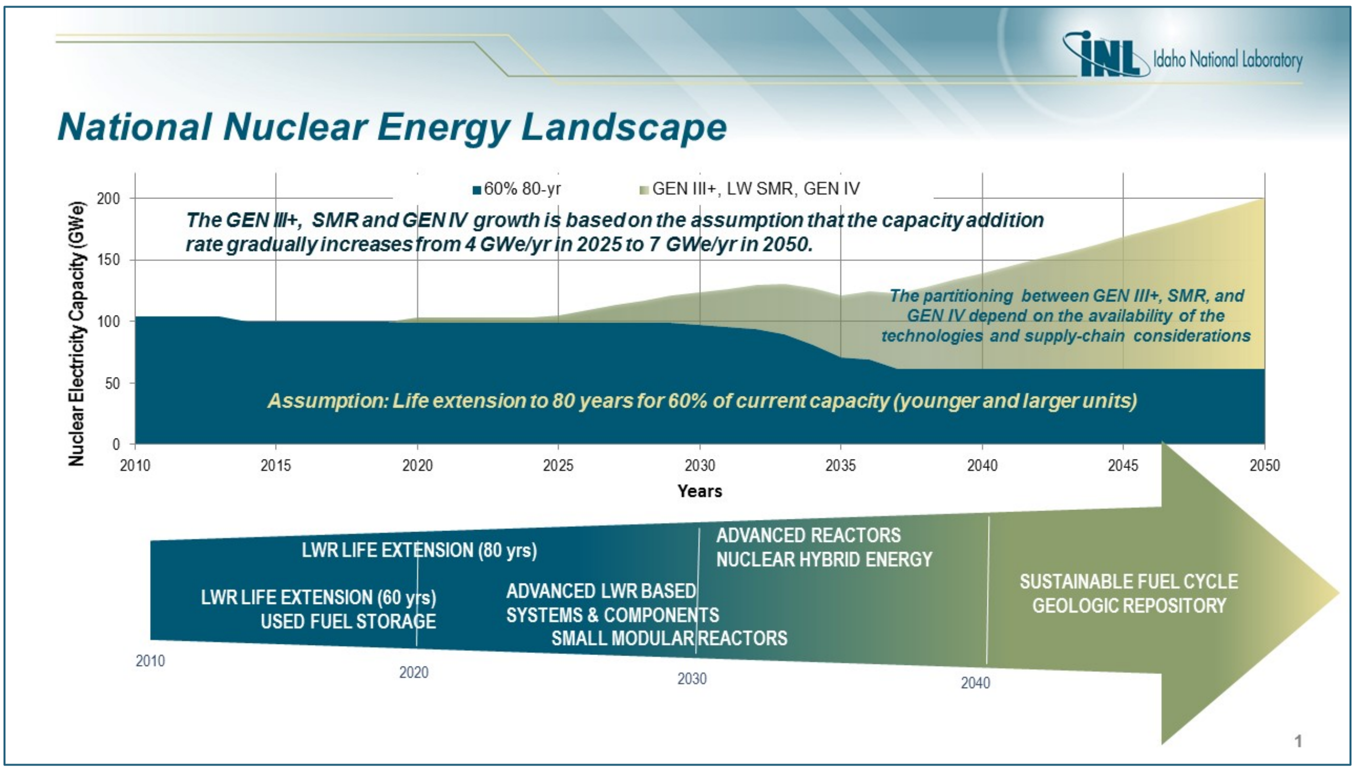
We have the rare opportunity to see over the horizon as we stand on the cusp of a fundamental transformation in energy use and the future energy mix. Nuclear energy technology innovation will be an essential driver for this transformation. The existing light-water reactor fleet will serve as a bridge to SMRs and advanced reactor technologies. We have developed tremendous expertise in operating LWRs at the highest levels of efficiency and safety, and much of that expertise will be relevant to advanced reactor design and operations.

It is impossible to predict the exact energy landscape a few decades from today. Policy choices and market dynamics will determine the exact landscape. However, it is clear that nuclear energy will play a critical role in a carbon constrained future energy scenarios. National security considerations will also become prominent with the increase in global interest in nuclear energy.

The U.S. will continue to research various scenarios. One considered scenario includes the vision of doubling the national nuclear energy capacity to 200 GWe between now and 2050. Under that scenario, we will see today's light-water reactors, SMRs, and advanced non-light-water reactors operating side-by-side. The assessment of that scenario also highlights the sense of urgency associated with developing the supply-chain and initial deployment of the advanced reactor prototypes. There is an urgent need to develop and deploy significant new and flexible nuclear energy capacity, starting now and ramping up significantly in the 2030-2040 timeframe as our current reactor fleet approaches retirement. This time frame also is critical for U.S. to establish industrial leadership in the global markets. The following figure illustrates the notional scenario along with high-level timeline for critical milestones.

INL and the national laboratories are playing a key role in providing the technical foundation for enabling the demonstration and deployment of SMRs and other advanced reactor technologies.

Notional Scenario



For More Information

Nuclear energy and advanced reactor systems:
https://factsheets.inl.gov/SitePages/NuclearEnergyFactSheets.aspx
Idaho National Laboratory: https://www.inl.gov
GAIN: https://gain.inl.gov
NSUF: https://nsuf.inl.gov