Developing and Deploying
Advanced Clean Energy Technologies

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Thank you, Chairwoman Capito, Ranking Member Whitehouse, and Members of the Subcommittee. I am Dr. Mohammad Khaleel, Associate Laboratory Director for Energy and Environmental Sciences at the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee. It is an honor to participate in this hearing with this distinguished panel today.

INTRODUCTION

Oak Ridge National Laboratory is the largest Department of Energy (DOE) science and energy laboratory, conducting basic and applied research to deliver transformative solutions to compelling problems in energy and security. ORNL's diverse capabilities span a broad range of scientific and engineering disciplines, enabling the Laboratory to explore fundamental science challenges and to carry out the research needed to accelerate the delivery of solutions to the marketplace. ORNL supports DOE's national missions of:

- Scientific discovery—We assemble teams of experts from multiple disciplines, equip them with powerful instruments and research facilities, and address compelling national problems;
- Clean energy—We deliver technology solutions for energy sources such as nuclear fission/fusion, fossil energy, solar photovoltaics, geothermal, hydropower, and biofuels, as well as energy-efficient buildings, transportation, and manufacturing;
- Security—We develop and deploy "first-of-a-kind" science-based security technologies to make the United States, its critical infrastructure, and the world a safer place.

ORNL supports these missions through leadership in four major areas of science and technology:

- Computing—We accelerate scientific discovery and the technology development cycle through modeling and simulation on powerful supercomputers, including Titan, the nation's most powerful system for open scientific computing (fourth largest in the world), advance data-intensive science, and sustain U.S. leadership in high-performance computing;
- Materials—We integrate basic and applied research to develop advanced materials for energy applications. The latest frontier in materials research is at the nanoscale—designing materials

atom by atom —and we leverage ORNL assets such as Titan and the Center for Nanophase Materials Science for breakthrough materials research;

- Neutrons—We operate two of the world's leading neutron sources that enable scientists and engineers to gain new insights into materials and biological systems;
- Nuclear—We advance the scientific basis for 21st century nuclear fission and fusion technologies and systems, and we produce isotopes for research, industry, and medicine.

As an Associate Laboratory Director at ORNL, I am privileged to lead a talented group of scientists and engineers as we address scientific challenges to advance America's clean energy future. At ORNL, our researchers work with many of America's best innovators and businesses to pursue scientific breakthroughs in sustainable energy such as nuclear power and other domestic sources; carbon capture, utilization, and sequestration; environmental remediation; electric grid security and resiliency; sustainable transportation; and energy efficiency for manufacturing, homes, and buildings. These efforts include:

- fundamental science that enables efficient and cost-effective carbon capture, utilization, and sequestration to support the use of coal and other fossil fuels;
- research and development of new, less costly methods to produce cellulosic biofuels that can advance a domestic, clean energy resource and strengthen rural economies;
- exascale computing for the discovery of new materials and acceleration of the technology development cycle;
- research and development of new materials and technologies for clean and sustainable energy;
- additive manufacturing research to deliver new rapid and low-cost innovations for various clean energy sectors and strengthen America's economic competitiveness;
- research and delivery of scientific solutions for greater energy efficiency for our nation's homes and buildings;
- advancements in transportation, in areas including battery research, biofuels, and the development of carbon fiber and other materials for more fuel-efficient and lower-emitting vehicles;
- research and development of technologies to ensure the nation's electrical grid is both secure and resilient, particularly as industry and the public install more renewable energy resources.

Our discoveries fuel the growth of science as well as the local, regional, and national economies. Our scientists and engineers work with many of America's best innovators and businesses to research, develop, and demonstrate cutting-edge technologies and to break down market barriers.

The expertise we have established enables broader contributions in clean, sustainable energy and energy efficiency research and development (R&D). As a result, in partnership with other DOE National Laboratories and universities, ORNL is well positioned for key contributions to achieve scientific breakthroughs and develop innovative technologies that will meet our nation's clean energy needs for the next generation.

BENEFITS OF CLEAN, RELIABLE ENERGY

Access to reliable and affordable energy is crucial to the U.S. economy and to our daily lives. Energy is not just a vital resource in America; it is also a key employer. About 3.6 million Americans work in the production and distribution of energy, and another 1.9 million work in energy efficiency, according to DOE statistics.

The advancement of clean energy ensures that the United States will have abundant, reliable resources for a robust economy while protecting the environment and health of its citizens. Reliable energy requires a diverse portfolio ranging from safe, clean nuclear and fossil fuel plants backed by carbon capture, utilization, and sequestration, to renewable resources essential to our domestic economic engine and our competitiveness abroad.

The challenge of ensuring our energy resources are clean and reliable requires sustained research and development. These transformative scientific discovery programs address technical and regulatory risk, improve economic competitiveness, develop the next generation of scientist and engineers, establish advanced facility capabilities, and address the entire fuel cycle. Rapid innovation will also be essential to achieve success on the time-scale needed to replace retiring generation capacity and to enable deployment of new technologies.

ORNL ADVANCES CLEAN ENERGY SCIENCE AND TECHNOLOGY

Today's briefing highlights the latest scientific research and cutting-edge technologies to meet current clean energy goals. I will focus specifically on how ORNL is advancing technologies for effective carbon capture, utilization, and storage, and for clean, reliable nuclear energy.

Nuclear power is the only baseload, carbon-free, 24-hour-a-day, dispatchable energy source that has been proven on a scale relevant to the needs of our society. Likewise, for a balanced and reliable portfolio of energy sources, carbon capture, utilization, and storage are critical to advance the use of coal and other domestic fossil fuels.

ORNL has a rich history as a leader in providing basic science for energy innovation. In World War II's Manhattan Project, ORNL helped usher in the nuclear age, discovering the best ways for harnessing nuclear power to provide electricity to a flourishing nation after the war. Today, our researchers hold leading roles in developing and using nuclear technologies and systems to improve human health; explore safer, more environmentally friendly power; and support science discoveries that address national challenges. Similar innovations and scientific leadership are needed for both fossil and nuclear energy sources to ensure the nation's energy security and competitiveness, a vibrant economy, and stewardship of the environment.

Carbon Capture, Utilization, and Sequestration

Carbon capture, utilization, and sequestration (CCUS) is a strategy to stabilize the increasing concentration of carbon dioxide (CO2) in the atmosphere. ORNL researchers have developed novel materials and methods for capturing, utilizing, and storing CO2 emitted from such sources as fossil-fueled power plants. CCUS technologies maintain a place in our energy mix for existing resources like coal and natural gas while supporting the transformation of carbon pollution into useful products. Recent research and technological breakthroughs include:

Capturing carbon from ambient air. ORNL researchers have discovered a new, low-cost method of capturing carbon directly from ambient air, offering a new option for carbon capture and storage that requires minimal energy and chemical input. The method uses a material that captures CO_2 from the air and binds it as a crystalline carbonate salt. Releasing the carbon from the crystal for underground storage is accomplished through mild heating. Releasing carbon in traditional methods involves heating captured materials to extremely high temperatures to release the gas, a process that often emits more carbon than is removed from the atmosphere. Scientists are using the Spallation Neutron Source at ORNL to analyze the carbonate binding in the crystals with the aim of designing the next generation of sorbents.

Converting CO_2 directly into ethanol. ORNL has developed a simple, efficient process to convert carbon dioxide directly into ethanol. The method uses a nanotechnology-based catalyst made from copper, carbon, and nitrogen, and applied voltage that triggers a chemical reaction. With the aid of the catalyst, we demonstrated a conversion to ethanol with a yield of 63 percent in the laboratory. The process operates at room temperature in water. In addition to removing carbon from the atmosphere, the process could be used to store excess electricity as ethanol. Doing so would help to balance a power grid supplied by intermittent renewable energy sources.

Fluid Interface Reactions, Structures and Transport (FIRST) Center. ORNL is leading FIRST, a DOE Energy Frontier Research Center, working with Argonne National Laboratory and seven universities across the nation to better understand how fluids and solids interact at the nanoscale to create new energy materials and processes. Understanding these interactions can advance new methods to convert CO_2 to fuels.

Subsurface Science for Energy and the Environment

The subsurface is critical to the nation's low-carbon, secure energy future. The subsurface environment provides hundreds of years of safe storage capacity for CO_2**,** and can serve as a reservoir for energy storage for power produced from intermittent generation sources such as wind and solar. ORNL R&D in this area encompasses:

Center for Nanoscale Controls of Geologic CO_2. ORNL works in two areas for this DOE center:

- **Sealing effectiveness in shales**. ORNL is researching the basic science of seal resilience in CO_2 leakage from below-ground carbon sequestration sites, determining which shale formations are ideal for secure storage.
- **Mesoscale modeling of the complex CO_2-brine-mineral system.** We are helping develop advanced, more reliable and robust models to predict how quickly mineral reactions occur in response to CO_2 sequestration—important for the long-term security of CO_2 storage sites.

Monitoring CO_2 sequestration using isotopes, tracers. ORNL, a key partner, utilized the power of natural (isotopic) and introduced perfluorocarbon tracers to decipher the transport of CO_2 injected into the subsurface. The methods were successfully applied with the injection of 8 million metric tons of CO_2 at the commercial Cranfield enhanced oil recovery site in Natchez, Mississippi. ORNL is using the resulting tracer dataset to calibrate and validate predictive models for estimating CO2 residence time, reservoir storage capacity, and storage mechanisms; testing injection scenarios for process optimization; and assessing the potential leakage of CO2 from the reservoir.

SubTER Program

Exploration of the subsurface environment is critical to a scientific understanding of its potential for both energy production and storage and for storage of carbon and environmental pollutants. To address these challenges, DOE formed the Subsurface Science, Technology, and Engineering Research and Development (SubTER) crosscut program. The program brings together stakeholders in fossil energy, geothermal, nuclear energy, environmental, and basic science focus areas.

Some of ORNL's focus areas supported by DOE's SubTER crosscut include:

- the use of high-performance computing and novel computational imaging techniques to better model and simulate the subsurface environment;
- developing neutron imaging and scattering techniques to understand flow through porous and fractured geological materials and deformation of geologic materials;
- developing and applying advanced materials to improve well construction techniques;
- developing materials and sensors that can withstand a harsh underground environment and allow for better reservoir characterization;
- mineral recovery from geothermal brines and produced fluids, including membrane, solvent extraction, ion exchange, and sorbent technologies.

Critical Interface Science Focus Area (CI-SFA). As part of the Subsurface Biogeochemical Research Program in DOE's Office of Biological & Environmental Research, ORNL is leading efforts to integrate hydrology, geochemistry, microbiology, and computational science to investigate mercury behavior in terrestrial ecosystems. The extensive research around mercury at ORNL could be readily transitioned to other areas such as carbon sequestration. For example, injection of supercritical CO2 into porous basaltic rock is designed to dissolve certain magnesium and calcium-rich silicate minerals to form calcium carbonate. This reaction occurs in tight, small pores differently than in large pores (pores that diffuse water easier). We see similar behavior when it comes to contaminated subsurfaces. Tight small pore zones often control contaminant release to groundwater.

Titan: Modeling Subsurface, Power Generation Applications

Researchers from around the country use the high-performance computing resources that are part of the Oak Ridge Leadership Computing Facility (OLCF) at ORNL to inform their research—including Titan, the nation's most powerful supercomputer. Scientists are already preparing for the 2018 launch of Summit at ORNL—expected to be the world's fastest supercomputer and five to 10 times faster than Titan.

Recent work in the clean energy space using ORNL's supercomputing resources includes:

Ramgen Power Systems CO2 compressor. R&D company Ramgen came to ORNL to test and optimize novel designs that use aerospace shock wave compression technology for gas compression systems, such as CO2 compressors. Efficient compression of CO2 could significantly lower the high cost of carbon capture and sequestration, supporting DOE's goal of $40/tonne of CO_2 captured by 2025. With assistance from the OLCF, Ramgen simulated precise design spaces and complex fluid dynamics that will affect compressor performance. Those simulations save the company millions of dollars and years of time by avoiding the creation and testing of a suite of prototypes.

Next-generation subsurface flow simulations. A team of researchers from Virginia Tech used Titan to study subsurface multiphase flows, or situations where materials are flowing close together in different phases (solids, liquids, or gases), and when the flow is composed of materials that have a common phase with a different chemical makeup that prevents mixing (such as oil and water). The result has been unprecedented insight into how materials interact in porous media such as soil. These models provide critical information needed to evaluate the efficacy of CO_2 sequestration in a given location.

Simulating the first coal plant with near-zero emissions. In a project for the National Energy Technology Laboratory, the OLCF simulated clean coal technology that would result in a combined-cycle, coal-fueled power plant with near-zero emissions of nitrogen, mercury, and that traps most CO_2. The modeling work helped avoid the cost of building expensive prototypes.

Mesoscale Simulation of Subsurface Fractured Materials. Researchers from Lawrence Berkeley National Laboratory led a project to use direct numerical simulation at unprecedented scale and resolution to model pore scale processes associated with carbon sequestration and to bring such knowledge to bear on the macroscopic scale of a reservoir. This first-of-its-kind work provides a better understanding of caprock integrity for subsurface carbon storage and of phenomena associated with fracture-induced oil and gas extraction from shale.

Large Scale Turbulent Clean Coal Combustion. A team led from the University of Utah is developing code within the Uintah computational framework to realize the goals of the Utah Carbon-Capture Multidisciplinary Simulation Center (CCMSC), a DOE center. These goals focus on enabling full machine utilization (CPU and GPU) of the largest possible large eddy simulations (LES) for oxy-coal boiler modeling. The outcome of this project will be an important step toward enabling petascale-simulated guided design for next-generation oxy-coal boilers for clean energy. Work done through the Utah CCMSC is in collaboration with Alstom Power.

ARM Data Archive

The Atmospheric Radiation Measurement (ARM) Data Archive at ORNL has as its primary objective an improved understanding of the fundamental physics related to the interactions between clouds and radiative feedback in the atmosphere. The project collects data about radiation, meteorology, water vapor, aerosols, and clouds. The ARM archive is intended to facilitate research on Earth's atmosphere, including monitoring and modeling of CO_2 and other emissions such as aerosols from combustion sources (diesel engines, biomass burning), known as black carbon. The archive collects and delivers about 17 terabytes of data per month, and serves nearly 1,300 registered scientific users from approximately 15 federal and state agencies and more than 200 universities. ARM and subsequent modeling work is supported by ORNL's high-performance computing resources.

"Big Ideas" for Carbon Utilization

Each year, the chief research officers of ORNL and the other National Laboratories gather to present and discuss transformative ideas for the energy future as part of DOE's Big Ideas Summit. At the Summit in March, these top scientists brainstormed ways to utilize industrial CO2 and other carbon-containing waste streams to create new carbon-based products such as carbon fiber for lightweight, fuel-efficient vehicles, transportation fuel additives, and specialty chemicals. At ORNL and other labs we are also studying the global nitrogen economy, including improving fertilizer production and use in plants as well as environmental effects in air, soil, and water.

ORNL ADVANCES NUCLEAR POWER SCIENCE & TECHNOLOGY

Nuclear energy is the largest clean-air energy source in the United States and the only source providing consistent around-the-clock power. It is a secure source that is not subject to changing weather conditions, unpredictable fuel cost fluctuations, or dependence on foreign suppliers. Nuclear power plants produce no air pollution and do not emit greenhouse gases. In the U.S. alone, nuclear power already provides almost two-thirds of our emission-free generation and about 20% of total electricity, according to the Nuclear Energy Institute.

To keep the existing fleet of nuclear power plants operating safely and to support the next generation of reactors, ORNL is focused on:

- advanced reactor technologies, including molten salt reactor technologies;
- next-generation materials for the temperature and radiation environments experienced in reactors;
- vital modeling and simulation capabilities;
- reactor design criteria for regulators to shepherd new nuclear reactors to reality.

The Next Generation of Nuclear Energy

ORNL's nuclear fission research and development efforts span the nuclear fuel cycle and address the current fleet, as well as future reactors. These efforts include:

- advanced reactor technology development and design;
- light water reactor sustainability;
- research and development of nuclear fuels—increased accident tolerance and understanding the science of used nuclear fuel;
- modeling and simulation, including integrated multiphysics modeling, developing new physics codes, and exploring exascale applications;
- measurement and analysis of nuclear data;
- understanding the science of materials in extreme environments;
- development of new manufacturing and maintenance technologies, and;
- safety analysis and licensing approaches.

Recognizing the challenges ahead in nuclear energy, we must nonetheless move forward deliberately and decisively if we are to avoid the nuclear cliff, which shows the rapid retirement of a large capacity in a relatively short period of time, potentially as much as ~100 GWe starting in the early 2030s, depending upon subsequent license extensions for some plants. This 21st century real and present threat creates an urgency that must be translated into action if we are to successfully modernize our nuclear power generating capacity on the needed timescale.

The CASL (Consortium for Advanced Simulation of Light Water Reactors) DOE Energy Innovation Hub Experience

CASL was established at ORNL to provide leading edge modeling and simulation capability to improve the performance of currently operating light water nuclear reactors. This virtual reactor simulation toolkit is supported by ORNL's high-performance computing resources.

The ORNL experience in conceptualizing, organizing, and executing the CASL mission to provide leading edge modeling and simulation capability to improve the performance of current operating light water reactors represents a valuable model. Many of the rapid innovation aspects discussed above were successfully implemented in the CASL methodology. Collaboration via partnerships across the government, academic, and industrial sectors of the nuclear energy community remains a core management principle of CASL, and multiple DOE National Laboratories (ORNL, Idaho National Laboratory, Sandia National Laboratories, Los Alamos National Laboratory) are founding partners with critical roles in addressing specific technical challenges. CASL has been a widely acknowledged success as a direct result of these practices.

CASL has been developing the **Virtual Environment for Reactor Applications (VERA)** software suite, which was recently recognized with an R&D 100 award. VERA simulates nuclear reactor physical phenomena using coupled multi-physics models including neutron transport, thermalhydraulics, fuel performance, and coolant chemistry. These CASL tools are now being used in several areas for reactor analysis related to confirmation of vendor analysis tools, analysis of reactor startups, assessment of the risk of Corrosion-Related Unidentified Deposits (CRUD) Induced Power Shift (CIPS), applications to investigate fuel performance, and special studies that provide the physics simulation and fidelity to address issues that industry codes cannot.

Test stands have been deployed at Westinghouse Electric Company, the Tennessee Valley Authority (TVA), and the Electric Power Research Institute to enable direct industry participation in the test and evaluation stage of CASL technologies.

Examples of CASL applications include:

- Simulation of 14 cycles (20 years) of TVA Watts Bar Unit 1; operation and simulation of Watts Bar Unit 2 startup;
- Westinghouse simulation of the AP1000™ startup and first cycle;
- CRUD and CIPS simulations by Duke Energy, AREVA, and NuScale, and;
- Modeling of accident-tolerant fuel designs at Westinghouse.

A Science-Based Design and Licensing Approach

With contemporary science-based tools and techniques, the development phase of advanced nuclear systems can be rapidly accelerated in laboratory and high-performance computing environments. Similarly, there are also opportunities to accelerate the licensing phase.

New materials. The materials selected for use in nuclear systems directly affect the economics, performance, and safety of power plants. The opportunity is now at hand to move to a new generation of reactors that will also employ a new generation of advanced materials that can increase safety while reducing cost.

Materials science advancements are essential—ORNL is a premier materials laboratory where we are researching ways to reduce the time from discovery to use. Additionally, we are exploring how to extrapolate short time experiments and measurements to the much longer times required for components in service. Scientific investigation with neutrons gives researchers unprecedented capabilities for understanding the structure and properties of materials important in biology, chemistry, physics, and engineering.

Energy Dissipation to Defect Evolution (EDDE). ORNL leads another DOE Energy Frontier Research Center, EDDE, in collaboration with Lawrence Livermore National Laboratory and five universities across the nation to develop a fundamental understanding of energy dissipation mechanisms in tunable concentrated solid-solution alloys, and ultimately control defect evolution at the early stage in a radiation environment; and to yield new design principles and accelerate science-based material discovery of radiation–tolerant structural alloys in the pursuit of new materials for nuclear energy.

Advanced Reactor Licensing — Regulatory Guide. ORNL researchers are lending their scientific expertise to help modernize and streamline the regulatory process for the design and licensing of new, advanced nuclear power plants. We teamed with Idaho National Laboratory and Argonne National Laboratory to develop initial drafts of advanced reactor design criteria (non-light water reactors) that were featured heavily in the recently issued U.S. Nuclear Regulatory Commission (NRC) draft regulatory guide (DG), DG-1330, "Guidance for Developing Principal Design Criteria for Non-Light Water Reactors."

This proposed new regulatory guide is to provide support for developing principal design criteria to designers, applicants, and licensees of advanced reactors. The criteria establish the design, fabrication, construction, testing, and performance requirements for structures, systems, and components that provide reasonable assurance that the facility can be operated safely. The multi-lab team collectively developed initial advanced reactor design criteria for advanced reactors. The advanced reactor design criteria are intended to be technology-neutral and, therefore, could apply to any type of non-light water reactor design. In addition to the technology neutral criteria, the researchers developed initial design criteria specifically for sodium-cooled fast reactors. The Idaho team developed initial design criteria for modular high-temperature gas-cooled reactors. The NRC is expected to issue the final guide by the end of 2017.

Modeling and Simulation, Materials Science, Advanced Manufacturing for Nuclear

In order to deploy new reactor technologies, we are using new methods such as increased use of modeling and simulation, use of advanced manufacturing techniques, and development of new materials.

Modeling and simulation. Modeling and simulation along with data exploration have joined experiment and theory as the third and fourth pillars of science, allowing researchers who make the most of supercomputers to quickly draw conclusions from complex and copious data. Large-scale computing underpins scientific disciplines including materials science, chemistry, plasma physics, astrophysics, biology, climate research, and nuclear fission/fusion. ORNL supercomputers and support systems for data generation, analysis, visualization, and storage illuminate phenomena that are often impossible to study in a laboratory. Simulations allow virtual testing of prototypes before their actual construction and speed the development of technology solutions.

Advanced manufacturing techniques. We are exploring new approaches to the production of qualified components for nuclear energy service, such as additive manufacturing, also known as 3D printing. We are utilizing VULCAN, an engineering materials diffractometer beam line at the Spallation Neutron Source, for in situ and time-resolved measurements to understand deformation, phase transformation, residual stress, texture, and microstructure of 3D printed components. ORNL is collaborating with equipment manufacturers and end-users to advance state-of-the-art technologies and revolutionize the way products are designed and built using additive technology. Drawing on its close ties with industry and world-leading capabilities in materials development, characterization, and processing, ORNL is creating an unmatched environment for breakthroughs in additive manufacturing.

Advanced Reactor Research

Part of ORNL’s nuclear power plant research focuses on the development of small modular reactors (SMRs) that have the potential to provide substantial energy output at a smaller scale. These reactors could significantly reduce the cost and therefore the up-front risk of licensing, construction, and operation of new nuclear power plants. SMRs can be tailored to local power needs, have a smaller geographic footprint, and require fewer operating personnel than large, conventional reactors.

DOE has established two advanced reactor projects, and ORNL is participating in both. We are partnering with industry and other institutions on:

Molten Chloride Fast Reactor. A project led by Southern Company Services, a subsidiary of Southern Company, focuses on molten chloride fast reactors (MCFRs). The effort includes ORNL, TerraPower, the Electric Power Research Institute, and Vanderbilt University. The liquid-fueled MCFR is a molten salt reactor design that offers advantages in terms of its simplicity, fuel cycle, and efficiency. Molten salt reactors are inherently safer than conventional reactors as they use a liquid fuel that is not at risk for meltdown. If a breach were to occur, the molten salt would simply cool and solidify, avoiding the release of radioactive byproducts to the surrounding environment. Compared to other advanced reactor concepts, MCFRs could provide enhanced operational performance, safety, security, and economic value.

X-energy-100 Pebble Bed Advanced Reactor. ORNL is also supporting a project led by X-energy to develop the fuel manufacturing methodology needed to supply the Xe-100 Pebble Bed Advanced Reactor. Partners on the project include BWX Technologies Inc., Oregon State University, Teledyne-Brown Engineering, SGL Group, and Idaho National Laboratory. The next-generation design, advanced safety features, and small footprint of the pebble bed high-temperature gas-cooled reactor will enable such a reactor to serve a wide array of community and industry needs while ensuring public safety.

CLOSING REMARKS

DOE's scientific and technical capabilities are rooted in its system of National Laboratories—17 world-class institutions that constitute the most comprehensive research and development network of its kind. The laboratories work as a network with academia, industry, and other federal agencies to ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions.

ORNL is actively engaged in helping address these compelling national energy challenges, and we are partnering with other laboratories, industry, and academia to enable the rapid innovation that will be required. We are ready to continue supporting the government's role in promoting scientific research, which has been a cornerstone of U.S. policy since World War II. Together, we can succeed in bringing the best of our nation's scientific understanding and engineering prowess to bear on deploying the next generation of clean energy technologies.

Thank you for the opportunity to share my thoughts with the Subcommittee. I request that my written testimony be made a part of the public record, and I would be happy to answer your questions.