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U.S. Senate Date: Tuesday, July 25, 2017

Committee on Environment
and Public Works Washington, D.C.

HEARING ON DEVELOPING AND DEPLOYING ADVANCED CLEAN ENERGY TECHNOLOGIES

Tuesday, July 25, 2017

United States Senate
Committee on Environment and Public Works
Subcommittee on Clean Air and Nuclear Safety
Washington, D.C.

The committee met, pursuant to notice, at 10:07 a.m. in room 406, Dirksen Senate Office Building, the Honorable Shelley Moore Capito [chairwoman of the subcommittee] presiding.

Present: Senators Capito, Whitehouse Inhofe, Boozman, Fischer, Ernst, Merkley, Gillibrand, and Markey.

Also Present: Senators Barrasso and Carper.

STATEMENT OF THE HONORABLE SHELLEY MOORE CAPITO, A UNITED STATES SENATOR FROM THE STATE OF WEST VIRGINIA

Senator Capito. The Committee will come to order. The Ranking Member is en route, I believe, and so, in the interest of everybody's time, I am going to go ahead and begin my statement.

Thank you all for being here today. Thank the Subcommittee.

I will begin by obviously recognizing myself for an opening statement and then Ranking Member Whitehouse when he appears.

Senator Alexander and Chairman Barrasso will then introduce witnesses from their home States.

Our hearing today will provide an opportunity for the members of this Subcommittee to learn more about advanced power generation technologies that will improve air quality and reduce carbon emissions.

The development and commercial deployment of these technologies will inform this Committee's consideration on clean air and nuclear safety regulatory and legislative proposals, and oversight of regulated agencies.

Our panel of expert witnesses has a diverse and deep wealth of experience dealing with research and development of advanced coal and nuclear technologies across the private and public sectors and academia.

I am particularly happy that Brian Anderson, who is the Director of the Energy Institute at West Virginia University, has joined us today. Dr. Anderson is extremely knowledgeable on fossil technology, research, development, and commercialization across academia and the national lab system and the private sector, so I look forward to hearing his insights.

The Federal Government has played a role in incubating important energy technologies for decades with the goal of commercial viability. These days, this development in coal and nuclear technologies is as important as ever.

The coal-fired and nuclear power generation sectors provide the core of this Country's baseload electricity, and both are under serious pressure as the result of a confluence of regulations, electric market inefficiencies, and competition from cheap natural gas.

Plants powered by both fuels are currently either being shuttered or pushed beyond their original planned ends of life at the cost of foregone investment, lost jobs, higher electric rates, and economic harm to upstream and downstream industries.

However, there is no clear reliable baseload alternative to these technologies. New high-efficiency coal plants with cleaner emissions streams to facilitate carbon capture and utilization, the development of advanced carbon-based materials and manufacturing processes, and the employment of advanced

nuclear reactor designs that are safer and more efficient than the Cold War era designs that will be replaced are all essential developments to ensuring the reliability of the grid.

The U.S. has a vast and diverse energy resource and a deep well of scientific and engineering talent. But instead of using these assets to great effect, over the last several years we have let those skills atrophy, leaving the major advances in these markets to foreign competitors due to a lack of policy vision.

As we consider agency regulations and congressional legislation dealing with emission standards and energy permitting, we must consider whether we are protecting ourselves into harm's way. If the Federal Government is funding advanced fossil and nuclear technologies with an eye to getting these designs into the marketplace, but is simultaneously creating regulatory structures that are not flexible or expeditious enough, we may actually smother those taxpayer investments in the crib. This will be a negative feedback loop, as unrealized reductions in emissions drive demands for tighter regulations.

West Virginia has both a great story to tell when it comes to the research and development of this technology, and a great deal at stake when it comes to the future of energy markets and regulation. We are a major exporter of energy, including electricity, to our neighboring States, and that sector is under

significant pressure.

The State is home to West Virginia University, which Dr. Anderson is representing, and the National Energy Technology Lab in Morgantown. Their presence has also attracted innovative and manufacturing companies researching more efficient power plant designs, fuel cells, carbon capture technologies and other technologies that will contribute to a manufacturing renaissance achieved with lower emissions of carbon dioxide and air pollutants.

Given the stakes of this policy debate for my State of West Virginia and the entire Country, Congress must be well informed about the development of new technologies in these fields, what they can and cannot deliver in terms of efficiencies, and how realistic their commercial viability is. That is the only way we can craft legislation and create meaningful oversight of federal agencies to achieve the best outcomes for American workers, families, and environmental quality.

Today's hearing will support that mission by giving voice to a panel of this Nation's foremost experts in the field. I look forward to hearing from our witnesses and the dialogue from our members.

I will now yield and welcome our Ranking Member, Senator Whitehouse, for his five-minute opening statement.

[The prepared statement of Senator Capito follows:]

STATEMENT OF THE HONORABLE SHELDON WHITEHOUSE, A UNITED STATES SENATOR FROM THE STATE OF RHODE ISLAND

Senator Whitehouse. Thank you, Chairman Capito. I am delighted that we are having this hearing and want to welcome my Chairman in the HELP Committee, Chairman Alexander, here.

Chairman Alexander invited me to testify in his Energy Appropriations Subcommittee last year, and he and I have worked together on promoting clean energy solutions, so I am looking forward to his testimony. His State is the home of Oak Ridge Lab, one of 17 exceptional national laboratories that we have spread across 14 States, employing thousands of scientists, and very strongly supporting the scientific consensus that climate change is real and that something needs to be done about it.

Along with our terrific State universities, these laboratories are centers of innovation. They have helped us explain photosynthesis, discovered 16 periodic elements, created the modern seatbelt, developed flu vaccines, redefined cancer treatment, and helped develop the Internet. We can be extremely proud of our national labs and of the relationships they have with our greatest universities.

Today we are here to learn about developments in homegrown clean energy technologies like carbon capture utilization and storage, and advanced nuclear, technologies that hold promise to transition the U.S. to a carbon-free future.

Of course, funding these labs is important. I won't dwell on this, but the President's budget is very inconsistent with the bipartisan support for our national laboratories, and I hope that our appropriators will see the wisdom of continuing to support the national labs.

Carbon capture research and nuclear programs have bipartisan support here in Congress as well. I recently joined Senators Heitkamp, Barrasso, and Capito on a bipartisan carbon capture utilization and storage bill to provide tax incentives to avoid carbon emissions. Senators Booker and Duckworth on this Committee are also cosponsors. Chairman Capito, Senator Inhofe, and other EPW colleagues also have a bipartisan advanced nuclear bill to reform the Nuclear Regulatory Commission licensing process for advanced reactors whose technology is being developed in our national labs. And last year Senator Alexander and I wrote an op-ed in The New York Times on the importance of our existing nuclear fleet to carbon-free energy and our effort to address climate change.

New energy technologies can move us closer to energy security, increase our global competitiveness, and improve the reliability of our energy grid. But what matters most to me is protecting my home State of Rhode Island, which is on the front lines of climate change. In our ocean State, we have almost 400 miles of beautiful coastline. West Virginia has beautiful

things, but not much coastline.

Senator Capito. Not much.

Senator Whitehouse. Everyone in Rhode Island lives less than a half hour from the shore. Warming, acidifying, and rising oceans endanger our Rhode Island coasts. Rhode Island's Coastal Resources Management Council projects sea levels to rise by between 9 and 12 feet along our shores by 2100 if we continue to do nothing about carbon emissions. That submerges downtown Providence, our capital city, and it reshapes our coastline into a new Rhode Island archipelago.

Innovative clean energy solutions to reduce emissions and stave off those disastrous effects are vital to me. I remain committed to reaching across the aisle and finding common ground in these pursuits. I look forward to hearing from our witnesses today.

And as we recognize Chairman Alexander, let me just say my trip to Oak Ridge was really remarkable. The people you have working there are extraordinary and the presentation that they give on climate change is extraordinarily compelling, well researched, and founded in the real science.

Thank you.

[The prepared statement of Senator Whitehouse follows:]

Senator Capito. Thank you, Senator.

We will begin the first panel. Our colleague, very well known to all of us, from Tennessee, Senator Alexander will be here to introduce the witness from Oak Ridge National Laboratory and to make some comments.

Welcome, Senator Alexander.

STATEMENT OF THE HONORABLE LAMAR ALEXANDER, A UNITED STATES SENATOR FROM THE STATE OF TENNESSEE

Senator Alexander. Thank you, Madam Chairman and Senator Whitehouse. Thank you for allowing me to introduce the witness and to make a few remarks beforehand.

As Senator Whitehouse said, he testified before our Energy and Water Appropriations Committee recently and, in a way, I am returning the favor, so thank you for that.

I am glad to be back before the Committee. Senator Carper and I were co-chairmen of the Clean Air Subcommittee, worked on it together for a number of years.

And so far as funding for the labs go, I think you will be pleased to know that the Energy and Water Appropriations bill approved last week, for the second consecutive year, had a record level of appropriated funding for the Office of Science, which funds the 17 national labs that we have.

Our Country has 99 nuclear reactors. They are capable of producing 100,000 megawatts of clean, reliable electricity with zero carbon emissions. If we were to close those 99 reactors, which provide more than 60 percent of our Country's carbon-free electricity, and replace them with natural gas plants, which history has shown is what usually happens when nuclear power is replaced, the emissions produced by these new natural gas plants would be the equivalent of placing nearly 118 million new cars

on the road. That is more than all U.S. passenger cars on the road today.

If you are concerned about climate change, as I am, that possibility is alarming.

While we normally think of clean nuclear power when we talk about climate change, it is more fundamental than that; it is also about jobs. The nuclear industry employs 100,000 people. They are high-quality, good-paying, career-long jobs. In South Carolina and Georgia, the four reactors currently under construction employ about 10,000 Americans.

If you are concerned about unemployment in the communities that support our existing nuclear reactor sites, the thought of losing these jobs is alarming.

Nuclear power is also about reliable electricity. Reactors operate over 90 percent of the time and provide reliable baseload power. We expect our lights to turn on in the morning and our air conditioners to work in the evening. Our manufacturers, which consume more than 30 percent of the Nation's energy, rely on electricity to produce goods 24 hours a day. Without reliable electricity, none of this would be possible.

So if you are concerned about manufacturing and supporting the 12 million manufacturing workers, losing nuclear power is alarming.

It is also about affordable electricity. Natural gas prices are low today. Less than 10 years ago, though, natural gas prices in the U.S. were at their highest ever. If we continue to replace closing nuclear plants with natural gas plants, it could lead to an increase in natural gas prices.

In 2014, an IHS energy report found that the diversified electricity supply in the U.S. lowers the cost of generating electricity by more than $93 billion a year. This means having nuclear, coal, hydro, natural gas all available. That lowers the cost of electricity. Losing this diversity could be very costly.

So if you are concerned about low-cost power, losing nuclear plants, which supplies 20 percent of our electricity, is alarming.

So I think we need to do something about nuclear power.

Over the last five years, six reactors have shut down prematurely. Analysts have warned dozens of additional reactors could shut down over the next 10 years, and in roughly two decades the U.S. could lose about half its reactors. That is because by 2038, 50 reactors will be at least 60 years old.

We could replace that lost generation with natural gas, but that could lead to an increase in prices and increased carbon emissions. Or we could replace it with renewables, but that would lead to considerable loss in reliability and could lead to

a large increase in electricity prices.

It would take a wind farm the size of Indiana to build enough wind turbines capable of producing the same amount of electricity as our current nuclear fleet.

The way I see it, we must replace the lost generation of nuclear reactors with new ones. If we continue to develop and be ready to efficiently license small modular reactors and advanced reactors, they could represent the future of nuclear power. They will be safer, produce less waste, and operate with higher efficiency.

Our next generation of reactors will not likely be possible without government funding, research, and support at the outset, which means we must double funding for basic energy research, which is about $5 billion a year today. We could pay for it by reducing subsidies for mature technologies, both for renewables and for fossil fuels.

I think the best way to lower the cost of energy, clean the air, improve health, increase family incomes, and produce jobs is double the funding for basic energy research. That means we must continue to support the good work of our national labs doing work on advanced reactors. I just mentioned the Appropriations Committee has recommended that to the Senate.

Dr. Moe Khaleel is here today to talk about the great work they are doing at the Oak Ridge National Lab in Tennessee. Dr.

Khaleel is Associate Lab Director for Energy and Environmental Sciences at Oak Ridge. In his role, he oversees the lab's activities that bring basic science to applied research and develop to support energy production, transmission, and conservation.

I thank the Chair and the Ranking Member not only for inviting me to introduce Dr. Khaleel, but allowing me to say those few words about what we can do to advance the next generation of nuclear reactors. Thank you.

[The prepared statement of Senator Alexander follows:]

Senator Capito. Thank you, Senator Alexander.

Now we will turn to Senator Barrasso, Chair of the full Committee.

Welcome.

Senator Barrasso. Thank you very much, Madam Chairman. I would like to take a moment to introduce Jason Begger, who has served as Executive Director of the Wyoming Infrastructure Authority since July of 2015. His past experience includes positions in the private sector and time as a staffer for the U.S. House of Representatives, where he handled energy issues.

In his current role, Jason oversees the development of the Wyoming Integrated Test Center. This center is now under construction on the site of a state-of-the-art coal-fired power plant outside of Gillette, Wyoming. When the Center comes online later this year, researchers will use the facility to test carbon capture, utilization, and sequestration technologies.

Those researchers will include finalists of the Carbon XPRIZE competition. The XPRIZE competition attracted 47 teams from seven countries to compete for funding to research innovative ways to convert carbon captured from coal plants into marketable products.

In my home State of Wyoming, we know coal provides affordable, reliable energy, and good jobs. Coal communities in

the Powder River Basin and the Green River Basin, and all across Wyoming, have been smothered by Federal overreach and regulation.

The State-led Wyoming initiative provides a path forward for coal, while spurring new technologies to transform carbon emissions into usable products.

Mr. Begger, I want to thank you for coming to Washington today. We look forward to hearing your testimony about this successful venture in Wyoming.

And I would also like to applaud the Chairman of this Subcommittee, Chairman Capito, and Ranking Member Whitehouse for holding this hearing so that the Subcommittee can explore policies that will help the Nation develop energy and make sure that it is as clean as we can as fast as we can.

Thank you very much, Senator Capito.

Senator Capito. Thank you. And I would like to welcome the witnesses.

Senator Carper. Madam Chair, could I just make a unanimous consent request? I would ask that my statement be included in the record.

And we have a special guest here from West Virginia, and I just want to say, as a native of West Virginia, we are happy that you are here. Give Gordon Gee my best. He has been President of West Virginia twice, Ohio State when I was an

undergraduate, Vanderbilt, Colorado. He has had a lot of --

Senator Whitehouse. Are you missing somebody?

Senator Carper. Brown?

Senator Whitehouse. Thank you.

Senator Carper. He has had a lot of jobs, but he has always had a good one. Give him my best, please. Thank you.

Senator Capito. Yes, without objection on your unanimous consent.

[The referenced information follows:]

Senator Capito. And we will have the witnesses take their place at the table.

Senator Whitehouse. And, Madam Chair, while the witnesses are getting seated, I would like to ask unanimous consent that the op-ed piece that I referenced in my opening remarks that Senator Alexander and I wrote, as well as an op-ed piece that I wrote with Senator Inhofe, Senator Booker, and Senator Crapo be added to the record of this proceeding.

Senator Capito. Without objection.

[The referenced information follows:]

Senator Capito. So now I will introduce or I will recognize the rest of our panel. And I think your written statements are in our materials, and you will be recognized for five minutes.

Our next witness is Dr. Brian Anderson, who I referred to in my opening remarks, and I am very pleased that he is here representing the Energy Institute at West Virginia University.

Welcome, Dr. Anderson.

STATEMENT OF BRIAN ANDERSON, DIRECTOR, WVU ENERGY INSTITUTE, WEST VIRGINIA UNIVERSITY

Mr. Anderson. So, first I would like to thank Senator Capito and Ranking Member Whitehouse, as well as Chairman Barrasso for having us here in this hearing.

And, Senator Carper, I will pass on my regards to President Gee.

What I would like to talk about today is a little of the research that we do at WVU and also some of the findings about the broader impacts of advanced fossil energy technologies on the potential for reducing climate-forcing gases into the atmosphere.

So, at West Virginia University we have 167 faculty members who are affiliates of the University WVU Energy Institute, and this is across many different areas of research in the University, 14 different colleges, in fossil energy, renewable energy, policy and the environment. If you may recall, it was our environmental team, the Center for Alternative Fuels, Engines and Emissions, that found that Volkswagen was cheating on their emissions regulations for the NOx emissions. We also have the Water Research Institute that is leading in the development of technology from taking acid mine drainage in our waters and extracting rare earth elements that support many renewable energy technologies.

In the renewable space, we are a leader in biomass, as well as geothermal, and in energy storage to enable renewable energy technologies into the grid.

But the focus of my five-minute testimony, the remaining three and a half minutes, is on fossil energy technologies, and really three major projects that we have going on at the University.

The first is the U.S.-China Clean Energy Research Center Advanced Coal Technology Consortium, which is a result of the U.S.-China Protocol signed in 2009 to reduce carbon emissions from all aspects of energy technologies. We lead the Advanced Coal Technology Consortium, along with Livermore National Lab and another couple national labs and universities, in developing clean energy technologies hand-in-hand with counterparts in China, and to this project we really focus on two different areas: efficiency of the current fleet, as well as new technologies to reduce the carbon footprint of coal power generation.

So increasing efficiency, there is one particular barrier I would like to draw attention to this Subcommittee and the Committee as a whole, is the New Source Review for coal burning power plants. With substantial improvements in efficiency, plants have to go through the New Source Review, and this is a significant barrier to the deployment of new, higher efficiency

technologies in the coal fleet.

In the areas of new technologies under the CERC program at WVU and across the world, our developments of technologies of chemical looping combustion, as well as oxy-pressure combustion, gasification, integrated gasification, combined cycle, carbon capture, and sequestration technologies, and we are able to witness the advances in these technologies that are occurring in China and, quite frankly, we are falling behind in the development of new materials for higher temperature power cycles that lead to higher efficiency coal burning generation. Any carbon CO2 molecule that is not emitted through efficiency is one that is equivalent to one that is captured and sequestered.

The second project I do want to draw attention to is called the Marcellus Shale Energy and Environment Laboratory. As we know, much of our power sector is shifting to natural gas, and there is a lot of natural gas and natural gas liquids being produced from the region in Appalachia. Our Marcellus Shale Energy and Environment Laboratory, called MSEEL, is the world's first transparent well in the sense that all the data collected in terms of its water footprint, its air footprint, noise, light, and the full cycle of the production of natural gas from this Marcellus Shale site in Morgantown is open to the public. This is one of the most instrumented wells in the world, and we have a full record of all of its emissions through the cycle,

with a design on reducing emissions during production, as well as emissions during transportation and distribution of natural gas.

And then the third project I do want to draw attention to is one called the Appalachian Natural Gas Liquid Storage and Training Hub that we have been working on for a couple of years now. This is trying to catalyze both the industry and lower carbon clean manufacturing, as well as the efficient use of our natural gas and natural gas liquids resources to reduce transportation costs, as well as the cost of the end manufactured product to consumers.

This particular project is one that we envisioned to catalyze the industry and the petrochemical industry in the Appalachian Basin in West Virginia, Pennsylvania, Ohio, and Kentucky, but do it in a fashion where the next generation of the petrochemical industry can implement new technologies that we are working on both at the University and our national lab partners.

So again I would like to thank you for inviting me here today, and I look forward to the questions the Committee would have. Thank you.

[The prepared statement of Mr. Anderson follows:]

Senator Capito. Thank you. Thank you, Dr. Anderson.

Our next witness is Mr. Jason Begger, introduced by his Senator from Wyoming. He is at the Wyoming Integrated Test Center. He is also Executive Director of the Wyoming Infrastructure Authority.

Welcome.

STATEMENT OF JASON BEGGER, EXECUTIVE DIRECTOR, WYOMING INFRASTRUCTURE AUTHORITY

Mr. Begger. Thank you. Madam Chairman, Ranking Member Whitehouse, Chairman Barrasso, members of the Subcommittee, I appreciate the opportunity to speak to you today about our carbon technology efforts in Wyoming.

Senator Barrasso gave a little bit of my background, but the Infrastructure Authority is a State instrumentality tasked with promoting and assisting in the development of energy infrastructure. Currently, our largest project is the Wyoming Integrated Test Center, which is a private-public partnership between the State of Wyoming, Basin Electric Power Cooperative, Tri-State Generation and Transmission Association, the National Rural Electric Cooperatives Association, and we have also received various sorts of in-kind contributions from Black Hills Energy and Rocky Mountain Power.

While we believe there is an important role for Federal Government to play in advancing technology, and we would welcome a partnership, not one cent of federal funding has been utilized at the ITC.

The ITC is a post-combustion, flue gas research facility located at Basin Electric's Dry Fork Power Station near Gillette, Wyoming. It will be the largest facility of its kind in the United States, delivering up to 18 megawatts worth of

scrubbed flue gas to researches testing CCUS technologies. The power plant will provide flue gas to five small research bays each capable of hosting tests up to 0.4 megawatts, and a large test bay that can host two demonstration projects with a cumulative total of 18 megawatts.

The distinction from the National Carbon Capture Center in Alabama is that their largest testing capabilities is only 1.5 megawatts.

Today, most post-combustion CO2 capture plants employ amine solutions. Boundary Dam and Petra Nova utilize amines; Technology Centre Mongstad in Norway, and the National Carbon Capture Center are leading research on solution-based CO2 capture. In Wyoming, we didn't want to duplicate work that was already being done; we wanted to compliment the other test centers by providing a place to scale up current research or look at other novel technologies.

One such technology that has received support from Wyoming is cryogenic carbon capture. The various components of flue gas freeze and vaporize at different temperatures. This technology involves freezing the flue gas and capturing CO2 as a frozen solid. Early tests have shown a 99 percent CO2 capture rate, costing less than $30 per ton, with a 15 percent parasitic load. The method has also proven to be very successful in removing sulfur dioxide, nitrous oxide, and mercury.

While we have seen promising results at small scale, further funding and testing is necessary to see this as a larger pilot project.

One of the most exciting partnerships that we have developed is with the XPRIZE Foundation. One of the best known XPRIZE competitions is the Ansari XPRIZE, which awarded the first team to fly three people to space and back twice within 14 days. One $10 million prize spurred 27 teams to invest over $100 million in technology development.

Eventually, Richard Branson licensed this technology to create Virgin Galactic, and today the private space travel industry is worth $2 billion, only 22 years after the idea for the competition was created.

The NRG COSIA Carbon XPRIZE will award $20 million in teams that are best able to convert CO2 into other valuable products. Currently, we have 23 teams from six countries that are in the second semifinal round, and they are working on ways to convert CO2 into things like carbon nanotubes, methanol, building materials, fish food, and plastics. The five finalists will test at the ITC with the goal of turning CO2 into an asset.

Technology should be apolitical, and the U.S. can make its greatest impact by investing in technology development that can be utilized around the world. There is considerable debate over the future of coal in the United States. However, every

credible energy analysis from the UN Intergovernmental Panel on Climate Change to the Department of Energy acknowledges that large amounts of coal will continued to be used globally for the foreseeable future. Technology is the best way to ensure these countries have access to power but, yet, can meet environmental goals.

I appreciate the opportunity to speak with you today and will gladly answer any questions. Thank you.

[The prepared statement of Mr. Begger follows:]

Senator Capito. Thank you very much.

I now recognize Dr. Steve Bohlen, who is the Global Security E-Program Manager at the Lawrence Livermore National Laboratory of California.

Welcome, Mr. Bohlen.

STATEMENT OF STEVE BOHLEN, GLOBAL SECURITY E-PROGRAM MANAGER, LAWRENCE LIVERMORE NATIONAL LABORATORY

Mr. Bohlen. Thank you, Senator.

Senator Capito. Dr. Bohlen. Sorry. It took you a lot of years to get to that.

Mr. Bohlen. Thank you. Thank you for giving me this opportunity to share our insights into the current status and future of carbon capture, utilization, and storage. My name is Steve Bohlen, and I lead the advanced energy technologies and energy security portfolios at the Lawrence Livermore National Laboratory.

Management of carbon dioxide emissions is not just viable; the technology exists today, is deployed and operating, and functions as designed. In addition, and perhaps most important, technologies for converting CO2 into useful materials and chemical feedstocks is developing rapidly. These provide new possibilities for a commercial enterprise in the United States, not to mention technical leadership.

Carbon capture, utilization, and storage is a growing, but underutilized element in the clean energy industry. CCUS, as it is known, includes carbon capture and storage, CO2 for enhanced oil recovery, CO2 for conversion and use as various products, and even carbon removal technologies which pull CO2 from the air and oceans. These different pathways provide many commercial

and environmental opportunities for companies, communities, and governments.

Technical progress in CCUS is significant with unrealized potential to manage carbon emissions. Today, 16 commercial plants operate worldwide, and 6 more will be operating in 2020. A third of these are in North America. Costs have come down, performance has improved, high-capacity sequestration has been demonstrated and proven to be safe, and new technologies have been borne.

Independent analysis shows that CCUS can be cost-competitive in certain markets with clean energy technologies. Together, these projects will inject 40 million tons of CO2 underground, equivalent to pulling 8 million vehicles off the road. I describe a number of these projects in some detail in my written testimony.

For nearly two decades, Lawrence Livermore National Lab has been funded to work on CCUS and has been a partner in most of the carbon capture sequestration projects nationally and globally. In addition, the lab has developed early stage technologies for CO2 conversion to useful products such as methane, methanol, and ethylene.

Livermore and other laboratories provide technical expertise, modeling and simulation, and actionable solutions for the challenges of enhanced oil recovery and carbon capture,

utilization, and storage. For example, today Livermore provides advanced 3-D fracture mechanics modeling for industrial partners for managing the risk of induced seismicity, for enhanced oil recovery, and underground carbon sequestration projects, as well as hydraulic fracturing, with the added benefit of using the same advanced tools for the monitoring of nuclear testing programs by our adversaries.

Lawrence Livermore National Lab scientists have provided technical and modeling expertise for large-scale geologic carbon sequestration projects globally, and the safe, long-term storage of several tens of millions of tons of CO2 underground.

In looking to the future, Livermore is engaged in the development of revolutionary new technologies with industrial partners to manage CO2 emissions by turning CO2 into valuable feedstocks for fuels and chemicals. In fact, we see a society that is poised at the edge of a new carbon economy, one in which CO2 is the driving force for new products and new enterprises in which innovation and entrepreneurships creates new companies and wealth by capturing and converting CO2 into value-added products.

Employing out-of-the-box thinking, the Lab is embarking on a bold new approach to manage CO2 at large scale, and simultaneously providing carbonate sands for cement manufacture and beach replenishment and elevation gain by extracting CO2

from seawater.

CCUS has many applications, including power, heavy industry, and as a pathway for achieving negative emissions. Though commonly considered a coal power sector technology, for which the technology would be most valuable in reducing emissions, the same or similar technology can be applied to biomass, natural gas, biogas, and even fuel cell power systems.

Many heavy industries, representing 20 percent of global emissions, lack other options to decarbonize. For cement, steel, petrochemical refining, and glass making, most of these emissions are a direct consequence of fabrication chemistry. To manage these emissions, carbon capture is currently the only viable option.

This concludes my testimony, and I look forward to your questions.

[The prepared statement of Mr. Bohlen follows:]

Senator Capito. Thank you very much.

Our next witness, as introduced by Senator Alexander, is Dr. Moe Khaleel, of Oak Ridge National Laboratory. He is Associate Lab Director for Energy and Environmental Sciences.

Welcome, Doctor.

STATEMENT OF MOE KHALEEL, ASSOCIATE LAB DIRECTOR FOR ENERGY AND ENVIRONMENTAL SCIENCES, OAK RIDGE NATIONAL LAB

Mr. Khaleel. Chairman Capito, Ranking Member Whitehouse, and members of the Committee, thank you for the opportunity to appear before you today with this distinguished panel.

Reliable energy is the foundation of our competitive national economy and our way of life. Reliable and sustainable energy requires a diverse mix of resources, including nuclear energy and fossil fuels.

To support a healthy energy portfolio that includes abundant domestic resources such as coal, oil, and natural gas, ORNL performs transformative science-driven solutions to better capture, utilize, and store carbon dioxide emitted from power plants.

Just in the past eight months ORNL announced two remarkable breakthroughs in carbon capture and conversion. We discovered a simple, reliable process to capture CO2 directly from ambient air, offering a new and potentially cheaper option for carbon storage. The method uses a simple compound that binds strongly with atmospheric CO2 and forms a crystal. The CO2 gas can later be easily separated from the crystal structure at mild temperatures. The new ORNL method offers a less energy-intensive alternative.

In another breakthrough, ORNL scientists created a new

catalyst that converts carbon dioxide directly into ethanol. It is very difficult to go straight from carbon dioxide to ethanol with a single catalyst. The process did so at high volumes, turning CO2 into ethanol with a yield of 63 percent in the lab.

These are just two examples of how ORNL's deep expertise in material science can be used to accelerate clean energy innovation.

We are also pursuing in our research a deeper understanding of the subsurface environment so we can better store CO2 and energy. Our scientists have used isotopes and tracers to decipher how CO2 moves into storage caverns. We have devised sensors for harsh environments and novel computational imaging to explore oil and gas reservoirs and to ensure well-borne integrity in drilling operations.

Our high-performance computing resources at Oak Ridge, like Titan, the Nation's most powerful supercomputer, have been essential to model and simulate the subsurface, and to test the clean coal technologies and compression systems used to store CO2.

For nearly 75 years ORNL has discovered the best ways to harness nuclear energy to provide electricity. The first nuclear power produced as electricity in the world came from the experiments with the Lab's graphite reactor in the 1940s.

The challenge is an urgent one. It is estimated that some

100 gigawatt of electricity could be retired in a relatively short period of time beginning in the early 2030s. ORNL is answering the challenge with leading research in the entire nuclear fuel cycle. From the development of new materials to new reactor technologies, our expertise and capabilities reduce the time from scientific discovery to usage.

ORNL's supercomputers support modeling and simulation of new materials and reactor designs. For example, the Consortium for Advanced Simulation of Light Water Reactors program at Oak Ridge was used to aid the startup of a new unit at the Tennessee Valley Authority's Watts Bar Nuclear Power Plant in October 2016. ORNL is pursuing scientific research of small modular reactors. These reactors can be tailor-made for specific local needs, requiring a smaller geographic footprint and fewer operating personnel.

We are also researching molten salt reactor technology. These reactors use liquid salt as a coolant and offer better safety margins than conventional light water reactors.

The national labs, including Oak Ridge, are uniquely positioned to address clean energy challenges with transformative scientific breakthroughs and to sustain American leadership.

Thank you for the opportunity to be here today and to share with you what we see as some of the solutions for a reliable

clean energy portfolio for the Nation. I welcome any questions you may have. Thank you.

[The prepared statement of Mr. Khaleel follows:]

Senator Capito. Thank you so much.

And finally we have Dr. Kemal Pasamehmetoglu. He is Associate Laboratory Director for the Nuclear Science and Technology Directorate at Idaho National Laboratory.

Welcome, Doctor. Thank you.

STATEMENT OF KEMAL PASAMEHMETOGLU, ASSOCIATE LABORATORY DIRECTOR, NUCLEAR SCIENCE & TECHNOLOGY DIRECTORATE, IDAHO NATIONAL LABORATORY

Mr. Pasamehmetoglu. Thank you, Chairwoman Capito and Ranking Member Whitehouse. I truly appreciate the opportunity to testify in this subcommittee today.

I was going to say a few words about the existing fleet and the value of nuclear energy, but I believe Senator Alexander did a great job in summarizing that, so I am quickly going to jump into looking into the future and what might be coming to meet the needs of twenty-first century energy.

As you know, there are a number of advanced reactor concepts that are being developed out there. They do have certain advantages compared to the existing fleet. I believe the existing fleet will continue to serve us well for a few more decades, but at some point we have to transition into those advanced concepts.

When we talk about advanced reactors, it is not just one type of reactor that we are talking about; there are multiple companies, private sector developing different types of reactors. The ones that are closer to deployment, I believe, are what we refer to as the small modular reactors that are cooled by light water. They do offer some advantages in terms of the manufacturability, as well as the inherent safety

features of those, but there are also reactors that are not cooled by water. Water has been the traditional coolant ever since we started nuclear energy production in our Nation, but there are some advantages to go to other types of coolants.

Those sorts of reactors are cooled by molten metals, sodium or lead. They operate at higher temperatures. They also offer certain safety advantages in terms of inherent safety. Then there are reactors that operate at even higher temperatures. They are typically cooled by either molten salt or helium gas; and those reactors not only have higher efficiency in terms of electricity production, but they can also be useful for process heat applications, so using nuclear energy above and beyond what we can do in the electricity sector.

And, finally, there is a set of reactors that combines the coolant and the fuel together. We refer to those as the molten salt fueled reactors. Basically, the fuel is dissolved in the molten salt and travels through the reactor core. They operate at high temperatures, as well, and they do offer some safety benefits just because the coolant and the fuels are combined together.

Overall, when we look at those advanced reactors, the advantages are economics, higher efficiency due to the higher temperatures, the inherent safety features, and fuel forms that they use that can benefit in terms of resource utilization,

wider range of applications in case of incidental conditions, and associated power conversion systems.

Now, I am sure you are all aware that there are multiple companies developing these technologies, but development of these technologies are expensive and require really expensive facilities for research and development. In November of 2015, Department of Energy announced an initiative. Shortly, we refer to it as the GAIN Initiative, which is Gateway for Accelerated Innovation in Nuclear, and its premise is trying to provide easy access for those startup companies to the capabilities that exist primarily at the government sites at the national laboratories.

In less than two years, I believe that GAIN has already made an impact in advancing some of those concepts considerably, or at least identifying the key issues.

In the last part of my talk, I just want to -- did I run out of time?

Senator Capito. You are getting close.

Mr. Pasamehmetoglu. I want to say a few words about Idaho National Laboratory. Very quickly, it is the lead nuclear energy laboratory; however, not all the capabilities require to advance these advanced concepts are located at Idaho. We create partnerships with other sister laboratories, universities, and industry to advance these concepts, and the larger experimental

facilities, such as the test reactor and the large hot cells and facilities where we need to deal with nuclear materials are located in Idaho, and they are being used today to advance these technologies.

[The prepared statement of Mr. Pasamehmetoglu follows:]

Senator Capito. Thank you. Thank you.

Thank you all very much.

Normally, I would begin the questioning, but I am going to yield to Senator Ernst. She has other obligations.

So, Senator Ernst, if you want to start us off.

Senator Ernst. Thank you, Chairman Capito. I appreciate that.

And thanks to our panelists as well.

As some of you know on this panel, Ames Laboratory at Iowa State University is home to the Critical Materials Institute, where the mission is to come up with materials that solve energy challenges related to clean energy. CMI focuses on five critical rare earths and two near-critical materials. Rare earths materials and other critical materials play a vital role in many modern, clean energy technologies, such as our wind turbines, solar panels, electric vehicles, and energy efficient lighting. Ames Lab has also done work in nuclear materials.

The Critical Materials Institute partners with four national laboratories, two of which are represented here today, so thank you very much.

And I would like to ask both gentlemen from the labs today, in your opinion, what sort of material development is needed to advance the next generation of nuclear reactors?

Mr. Khaleel, if we can start with you, please.

Mr. Khaleel. Sure, Senator. I think, you know, for the next generation of reactors, one needs materials, as Dr. Kemal mentioned, that can actually survive harsh environments at high temperatures. So the national labs, broadly speaking, really have these capabilities in terms of advancing new materials, and also new manufacturing technologies where some of the parts can actually be born both certified and qualified. So we can reduce the costs and reduce prototyping in these kind of technologies.

Senator Ernst. So, very important work for the labs, correct?

Mr. Khaleel. Absolutely. Absolutely.

Senator Ernst. Yes. Thank you.

Yes, please.

Mr. Pasamehmetoglu. As I have indicated, most of these advanced reactors would like to operate at higher temperatures for efficiency purposes, and, also, trying to make the reactors more and more compact requires that it has to be resistant to higher radiation damage. So the type of materials that we need to design for the future need to be able to operate in those harsh environments. Typically, we have the technologies to be able to design materials like that. The issue is always it takes a long time to qualify those materials and get them for commercial use, so a big part of the research that the national laboratories are conducting, including modeling and simulation,

is to see how we can accelerate that qualification process and bring them from concept to commercialization faster.

Senator Ernst. Very good. And it is truly a cooperative effort between all of those labs, then, as well.

Mr. Pasamehmetoglu. That is correct.

Senator Ernst. Thank you very much.

Mr. Bohlen, I understand that Lawrence Livermore National Laboratory is working with Iowa State University on an effort to convert forestry waste to biofuels. Can you tell me just a little more about this and how that partnership with Iowa State is going?

Mr. Bohlen. Yes, ma'am. Thank you, Senator. It is a great partnership and it is funded by the California Energy Commission. And it is not an insignificant investment by the State; it is almost $7 million.

It is a partnership that grew out of the State's need to deal with the hundreds of thousands of trees that died during the seven year drought. And there is a delicate balance between ecosystem health and fire health, and a not insignificant amount of the carbon emissions from the State come from forest fires. So there is a fast paralysis, so it is a process that involves heat, and can be conducted very rapidly, to convert forest waste, and that is everything from sawdust to trees that are pulled from the forests, into a biofuel.

And Iowa State has a process that can be delivered on two skids, essentially tractor trailer containers, that are delivered. The entire process is there. We are partnering with Sierra Pacific, as a forest manager, and we provide the lifecycle analysis to actually demonstrate that there is true carbon savings and the carbon pathways is a negative carbon pathway.

So it is a really great example of the labs working with universities, working with private industry to solve a very significant problem, and it is funded by the California Energy Commission.

Senator Ernst. That is fantastic. And I love to see that there is so much collaboration amongst so many groups out there, so thank you for your contributions.

To all of you, thank you very much.

Thank you, Ms. Chair.

Senator Capito. Thank you.

Senator Whitehouse. Thank you, Chairman.

Since Iowa State has been mentioned, let me reference an Iowa State University professor who recently told a United Nations conference that climate change was already affecting Iowa farmers. "This isn't just about the distant future," he said. Iowa State has published extensive research, one report titled "Global Warming: The Impact of Climate Change on Global

Agriculture."

And Iowa State has a prestigious Leopold Center that, to quote them, views climate change not merely as "warming, but as a worsening, destabilization of the planet's environmental systems." Sounds pretty serious. And it warns that it will create aggravated and unpredictable risk that will challenge the security of our agricultural and biological systems.

Iowa State's Leopold Center concludes, "The scientific evidence is clear that the magnitude of the changes ahead are greater, the rate much faster, and the duration of climatic destabilization will last much longer than once thought."

And Iowa State University is not unique. If we go to our Chairman's University of Wyoming, you would find the University of Wyoming Center for Environmental Hydrology and Geophysics reporting that many of the most pressing issues facing the western United States hinge on the fate and transport of water and its response to diverse disturbances, including climate change.

University of Wyoming scientists are publishing articles on the effects of projected climate change on forest fires' sustainability. The University of Wyoming is awarding university grants to study the effects of climate change on pollinators, on water flow, on beaver habitat, and on white bark pine growth. And, indeed, the University of Wyoming even has

its own University of Wyoming Climate Action Plan committing the University to reduce its carbon footprint, to expand climate research, and to demonstrate leadership as a charter member of the American College and University President's Climate Commitment.

If you go to West Virginia, which has, as I said, not much coast, but serious concerns about rains and flooding, the West Virginia University Mountaineers have a Mountain Hydrology Laboratory which tells us climate change has important implications for management of freshwater resources, which include that the highlands region in the central Appalachian Mountains is expected to, to use their phrase, "wet up." Warmer air carries more moisture, leading to what West Virginia University is calling this intensification of the water cycle. The laboratory warns that the implications of this intensification are immense. And, of course, West Virginia has seen rain-driven flooding.

West Virginia University's Wildlife Conservation Lab publishes regularly on climate change effects, and one of West Virginia University's climate scientists, Professor Hessl, has been recognized by West Virginia University as West Virginia University's Benedum Distinguished Scholar.

Hard to believe this isn't serious when these recognitions are going out.

West Virginia University even sends people all the way to China to study climate change.

And, of course, our distinguished national laboratories appear to be unanimous in the view that climate science is serious.

I would ask, for the record, to put in a presentation that Oak Ridge National Laboratory put together through its Climate Change Science Institution.

Senator Capito. Without objection.

Senator Whitehouse. And it is called Climate Change Science Institution Overview.

[The referenced information follows:]

Senator Whitehouse. So it is nice to have scientists back here in the panel again, and I think every single one of the institutions here has a demonstrated record of understanding that climate change is serious and that it is significantly manmade, and that its consequences are going to be very impactful if we don't get ahead of it by dealing with the carbon dioxide that is at the heart of the problem.

So I will close with a question for the record to all of you. I have been up to Saskatchewan and I have seen the amino rain technology, basically pumping exhaust through an amino fog to extract carbon dioxide. It is working and it is being compensated with oil extraction.

I have been out to Shenandoah, Iowa to see the ethanol plant where they are extracting algae from the waste stream using both waste heat, wastewater, and exhaust to feed algae, which then have marketable uses.

I have not been to Iceland, but I am familiar that they have a geologic sequestration facility there where they are pumping carbon dioxide into the ground, which has a geological formation in which the carbon dioxide actually turns to rock down there, so it is fully and thoroughly sequestered.

And, finally, that in Switzerland there is a direct air capture facility. It is not taken out of the waste stream, it is taken out of the air, but it is powered by waste heat. And,

in return, what they get is carbon dioxide that then can be compressed, put into tanks and sold into the commercial gas stream.

If there are other technologies, I would love to get your answers in writing as to what the other technologies are, with an evaluation of how promising they are.

And, Mr. Bohlen, if you could focus particularly on the ocean technologies, that would be of great interest to me.

But my five minutes has expired, so let me leave it at that. I will have other questions for the record, as well.

This is a very impressive and distinguished panel, and I thank the Chairman for bringing them in.

Chairman Capito. Thank you. Thank you.

Senator Inhofe.

Senator Whitehouse. I even have a few bits on the University of Oklahoma, but I ran out of time.

Senator Inhofe. No, I have some good ones from the University of Oklahoma, but since you brought it up, let me just make one comment about it. Nobody questions that climate has always changed; all evidence, all scriptural evidence, all archaeological evidence. We all understand that.

But I also would quote another great scientist, Richard Lindzen, with MIT, who said regulating CO2 is a bureaucrat's dream. If you control climate, you control life.

So, back in 1995 was my first year here in the United States Senate, and I was on this Committee, and at that time I actually chaired it. It was called then, I guess it still is, Clean Air and Nuclear Subcommittee. And at that time we had gone, I think, 12 years, 12 years without having any kind of a hearing on the NRC. Of course, we immediately got involved in that and kind of revived them, because you can't do that with any bureaucracy; you have to stay on top of it. So we did, and we have been very much interested.

It is interesting, because that is the only area where I think that Senator Whitehouse and I agree, that nuclear is so incredibly important for us to have in the mix.

Now, last month there is a magazine, an article in the Business Insider, published, article detailing seven different ways the United States is falling behind when it comes to nuclear power technology. Some of you may be familiar with this, and I would ask that this be part of the record at this time.

And while we are correcting the dependency problem that we had actually with the shale revolution in oil and gas, we are still increasing our dependency in other areas. Of course, one is importing uranium from Russia and purchasing heavy water from Iran. The United States can't afford to lose ground to countries like Russia, Iran, China, and other countries.

I would like just to ask you guys, particularly from the labs, what you think about this and why it is that we cannot get back in a position where we -- I understand that we have actually not had heavy water here since 1996 and have been importing uranium from Russia, about 20 percent, I think, of our mix right now is imported from Russia.

Does that sound right to you, either one of you?

Mr. Pasamehmetoglu. Yes, sir.

Senator Inhofe. Okay. Now, what can we do to -- I am concerned about that as a national security issue. I am concerned about that for other reasons other than just advancing without creating a problem in trying to get back in a leadership position in nuclear energy. What can we do about those two importations apparently that are still prevalent today?

Mr. Pasamehmetoglu. Senator, part of the uranium importation was to reduce the stockpile of weapon-usable uranium and down blending it. So it was, in terms of national security, I believe it was beneficial. However, as we look to the future, those advanced reactor concepts that I have mentioned, quite a few of them require enrichment higher than what we are capable of doing today. The standard light water reactors use 5 percent enrichment, and all our enrichment capabilities, commercial enrichment capabilities are limited by 5 percent. But the liquid metal coal reactors, as well as those high temperature

reactors, will require enrichment up to 20 percent.

So, at some point, if we are serious about advancing those technologies and taking the leadership in those technologies globally again, we have to look at the enrichment issue and the uranium issue very seriously.

Senator Inhofe. Are we doing that now? Are we looking at it? Are we trying to make it advancements? Because when I see that other countries now are passing us up, as pointed out in this article, in technology, and you say that we need to be looking at that, are we in the process now of trying --

Mr. Pasamehmetoglu. Department of Energy is looking at the options on how we can start supplying uranium enriched higher than 5 percent.

Senator Inhofe. Well, you know, for some of them we talk about, yes, we need to get back to where we have everything renewable and all that. I go back to my State of Oklahoma and they ask questions there they don't ask in Washington, like, you know, if we are dependent upon fossil fuel and nuclear for 89 percent of the power it takes to run this machine called America and you do away with both of those, how do you run the machine? And the answer is you can't.

What do you think, Mr. Khaleel? Are you optimistic that we are going to be able to do something in the future to put us back getting into technologies at least on an even keel with

some of our competitors out there?

Mr. Khaleel. I think so, Senator. You know, currently, the Department of Energy is pursuing these advanced reactors, non-light water reactors. And as Dr. Kemal mentioned earlier, there is a variety of concepts, and I think that really is an important thing, you know, in terms of our security, but also our competitiveness.

Senator Inhofe. Yes.

Mr. Khaleel. Likewise, modular reactors, they are really a good and a cheap way to trying to get to deliver nuclear power, sustained power in really a modular way, but also situated to the local conditions. So these two kind of approaches and activities are fairly important.

We also have enrichment, uranium enrichment activities at Oak Ridge National Lab. So I think we are pursuing multiple tracks.

I think an important thing is really to deal with the whole balance between finances and licensing, and also to bring modeling and simulation capabilities to accelerate the cycle for licensing in the U.S. I think that really is an important aspect that needs to come through, and I think most of our national labs have tremendous capabilities in modeling and simulation. These are high-fidelity predictive tools that can actually enable us to do things in a rapid way, and I think that

is critical.

Senator Inhofe. Well, I appreciate that. We had a Commerce Committee meeting at the same time that this is going on, so I missed the opening statements, and some of these things, I am sure, were covered. But that has been my interest for a long time, to make sure that we get back. I look at countries like France, and the percentage of their total energy provided from nuclear, and I can't see, looking into the future, how we are going to be able to do it without becoming more aggressive than we have been, more competitive in technology, too. Very good.

Thank you, Madam Chairman.

Senator Capito. Thank you, Senator.

Senator Carper.

Senator Carper. Thanks, Madam Chair.

When I read through your testimony in preparation for today's hearing, I thought to myself, boy, what an all-star lineup. And you have not disappointed. This is an exceptional panel and we welcome each of you.

Dr. Bohlen, you mentioned in your testimony something that always commands the attention for a lot of us on the East Coast who have coastal beaches, and that was the possibility of somehow addressing beach replenishment and using CO2 to bind up part of that process. You mentioned that was embryonic at this

point in time. I will ask you a question for the record. I will ask you to go into that in a little more detail. But my ears perked up when you said those words, so thanks for that.

I hosted a visit yesterday, along with Senator Coons and our Congresswoman Lisa Rochester, in Delaware, a visit from our Secretary of Agriculture, who is a recovering governor like I am, and he spent a big part of the day with us at the Delaware State Fair. We pulled together in the morning a roundtable that included 30, 40 people from the agricultural sector in our State. And we raise more soybeans, I think, in Sussex County, Delaware than any county in America. I think we raise more lima beans than any county in America. We raise more chickens there than any county in America. So Delaware, which most people don't think of as a big ag State, really is, and we punch above our weight, if you will.

One of our farmers who was there raises a lot of peaches and other fruits, but also raises corn. But he spoke passionately, and surprisingly to me, about the threat that climate change poses to his business, his farm business. Among the crops that he raises, he raises peaches, and he said when the blossoms on his peach tree bloom in the middle of February, that is not good. And he said for years he could almost set the clock by when they are going to start harvesting particular commodities in the middle part of August, and that date

continues to move up, up, up, up, up.

A lot of times, in my State, the real threat from climate change is sea level rise. But I just would share with you his words, and it makes all the more important some of what you are sharing with us today.

The Administration, current Administration, often uses what I believe is questionable information to defend the President's decision to walk away from the Paris Climate Agreement. For example, the Administration claims that the U.S. has made great strides in reducing greenhouse gas emissions over the past 14 years without government intervention. I think a closer look at that suggests that his comment ignores the facts on the ground.

I want to make three points, then ask a question.

First of all, the Federal Government has been regulating greenhouse gas emissions for our largest source, that is, mobile sources, for some eight years. Other clean air regulations targeting sulfur dioxide, nitrogen oxide, and air toxic emissions from our Nation's power plants have also had a co-benefit, as you know, of reducing greenhouse gas emissions.

Second point, the Federal Government has incentivized investment in clean energy through the tax code for decades. I submitted a statement for the record. In that statement I mention that the Federal Government has had a long-term production tax credit for alternative means of natural gas,

which helps lead to the natural gas boom that we enjoy today. And then, of course, there are the tax credits that the Congress has provided for a whole host of clean energy technologies in the Recovery Act of 2009, and tax-extended packages in 2012, 2014, and 2015.

Third point, then I will ask my question. The Federal Government has funded research on a host of clean energy technologies that have made these technologies cheaper and easier to develop and deploy.

Here is my question. How important have Federal Government actions been over the last decade in providing what I describe as a nurturing environment for clean energy investments and job creation, and what more can our Federal Government do and should we be doing?

Our West Virginia compadre, I will ask you to lead off. Dr. Anderson.

Mr. Anderson. Senator, thank you for the question. Investments in technology development through the Department of Energy, both in individual clean energy technologies like wind, solar, biomass, geothermal, etcetera, have certainly played an important role in deployment, as have the ITC and PTCs. In the fossil energy space, I would say that investments in carbon capture and sequestration technologies, as well as advanced power generation cycles have certainly created an environment in

which technologies are being developed. However, we are at the stage now where, if you consider technology readiness level and system readiness level, the next generation of deployment investments come at integrating the systems together. We have seen some challenges in terms of certain components of systems, but we are at the stage where large-scale carbon capture and sequestration technologies are ready to be developed and deployed, but there are some challenges at the system level, and that takes considerably large investments in dollars to deploy large-scale demonstration projects, and that is the hurdle we see next.

Senator Carper. Thanks very much.

Again, the question, what more can the Federal Government be doing, should be doing?

Please.

Mr. Begger. I guess, Madam Chairman, Senator Carper, you know, I think the Federal Government can do a couple things. One is we need to impose sort of realistic timelines. From utility industry perspective, when you looked at the deadlines of the Clean Power Plan, 5 to 10 years was just literally an impossibility to develop technologies, commercialize it, and employ that. So we need to understand what is a realistic timeline to deploy these technologies.

We also need adequate resources. You know, if you look at

I guess the mark for the energy and water appropriations fossil energy account, it is roughly about $500 million a year, all to do some of these larger scale technologies, Petra Nova, boundary dams and these things. Those are billion dollar plusses. So the real challenge is starting to integrate these different systems.

We understand that they work really well in small capabilities on their own, but when you start plugging them together, that is what the great unknown is. So we do need to provide those resources to scale things up.

And then also certainty. A power plant, utility that goes and builds a new coal-fired power plant today has a 60-year depreciation schedule, so I have been asked questions like why are we not seeing a new rush of coal-fired power plants with this Administration. It is like, well, a four- or eight-year presidential administration doesn't provide the regulatory certainty moving forward. So the sooner that the Federal Government can sort of provide that clarity and understanding of what they are going to do, I think that is going to give utilities comfort in adopting new technologies and moving forward.

Senator Carper. All right, thanks.

My time has expired, Madam Chair, but if we have a second round, could I finish my question?

Senator Capito. Okay. That would be fine. Thank you.

You kind of hit on the question that I wanted to go to initially. Senator Whitehouse mentioned that we just introduced, with 23 colleagues, a bill to reauthorize and expand the 45Q tax credit for carbon capture utilization and storage. We had strange bed fellows on that. Not only are Senator Whitehouse and I on this Committee and some of our fundamentals at odds with one another who we are representing, Senator Barrasso at the same time, and we were all on this bill to try to figure out the best way to move forward with this broader commercialization of the CCUS, and you sort of alluded to this, Mr. Begger did.

So I would like to ask Dr. Anderson, and you alluded to this as well in your opening statement. You mentioned that New Source Review was a regulatory burden to commercialization. My question is how much of the challenge is financial; how much is regulatory. I don't know if you want to expand on that a little bit, between the financial and regulatory. That is what I am trying to get to, as Mr. Begger said, to get the challenge at the system level.

Mr. Anderson. Right. And I agree with what Mr. Begger mentioned in terms of system integration, as well as one of the major challenges, as I mentioned in my statement, in terms of New Source Review. In terms of the financial challenges, it is

that certainty in the regulatory environment to be able to create a consistent demand side pool for the development of technologies. So I think that the 45Q is a great step in that direction, as long as we can create a playing field in terms of putting, whether it is a price on carbon, in terms of evening up the playing field between investment tax credits, production tax credits, and things like 45Q. If we can have a system in which it is much more predictable for the investment community, it would provide that opportunity to develop and deploy technologies.

Senator Capito. Does anybody else have a comment on that, the regulatory versus financial? Yes, Dr. Khaleel.

Mr. Khaleel. There was a study in 2013 that surveyed over 260 experts in the carbon capture and sequestration area to learn about obstacles and challenges. The number one obstacle was cost; number two, legislation; and I believe number four, regulation. So I think, you know, to decouple, really, the issue of finance and regulation is a little difficult, but as technologies move forward, then there is a need, a certainty to license these technologies, and that becomes very important. The uncertainty in the licensing process drives some of the finances and makes it really difficult. So I think it is really important to deal with the risk associated with licensing.

And, at the same time, when you look at costs, to drive

costs down, really, one needs to do a more R&D in that space and at the same time maybe, you know, a role that the Government may play in accelerating some of the deployment. That will be actually the case when one looks at the nuclear area, the modular reactors. But I would argue it may be also applicable in the carbon capture situation.

Senator Capito. Okay, let me ask a question on the utilization issue. No, let me backtrack here. I want to ask about utilization, but I want to ask about this ambient air.

Many of you mentioned the research going on removing carbon from ambient air. So, to me, that means not something at the power plant's source, but actually out, I don't know, on the highway or wherever that would happen to be. Am I correct in assuming that is what ambient air, that is what mean, just in general?

So I guess what I am asking is do we see this as the new frontier, this ambient air carbon removal? And again it comes back to, then, the utilization portion of it.

Dr. Bohlen, did you mention that in your comments?

Mr. Bohlen. I did mention that, Senator, and there are already commercial entities that are extracting CO2 from the air. Climeworks is a company in Switzerland. They are extracting CO2 from the air.

Senator Capito. What are they doing with it when they

capture it?

Mr. Bohlen. They are compressing it and selling it, actually, to greenhouses to encourage plant growth in very, very large, many, many acre-sized greenhouses.

Senator Capito. Okay.

Mr. Bohlen. So it is a very leading edge technology. The Climeworks executives feel that they can make money at $200 a ton CO2, I believe is the number. So it is not yet going to spread commercially worldwide, but it is a leading technology. People are working very hard to reduce the risk and uncertainty of how this is done, because it turns out that it is the CO2 itself that may actually become a more valuable product as we learn about catalysts and so forth to convert it into feedstocks that we currently now make out of petroleum.

Senator Capito. Well, thank you. I have always sort of had this vision. Being a coal State, obviously it is a big concern of mine that CO2 is going to have that value, that there is something either on the cutting edge of being researched and developed at the end of the supply chain that all of a sudden it becomes that looping back in.

So is WVU doing research on the ambient air?

Then I will turn to the next Senator.

Mr. Anderson. Not directly on the ambient air. As Dr. Bohlen mentioned, in terms of the cost, it is higher

particularly because it is much more dilute than ambient, so it suffers from thermodynamics in terms of trying to concentrate it. It is like we have a lot of gold in the ocean and we could concentrate it, but it is probably better to find a gold mine.

So when you have a point source that is a coal burning power plant with a much, much more concentrated stream of CO2, it is more efficient and lower cost to do it that way.

Senator Capito. And probably the best place to start, in any event.

Mr. Anderson. It would be the lowest hanging fruit, for sure.

Senator Capito. Senator Markey?

Senator Markey. Thank you, Madam Chair.

Today's hearing is about the development of advanced clean energy technologies, and we should be talking about the next frontiers in the clean energy revolution, but we also have to continue to support the revolution that is underway right now. The testimony submitted by our witnesses focuses on carbon capture and nuclear technology, and I am very open-minded when it comes to climate change solutions.

When Henry Waxman and I constructed the Waxman-Markey bill that passed the House of Representatives in 2009, we actually included $200 billion for carbon capture and sequestration in that piece of legislation. Now, it was part of a comprehensive

bill that dealt with all aspects of climate change, but it was clearly an ingredient. And the bill, as well, was endorsed by the Nuclear Energy Institute. So clearly a low carbon goal would establish incentives for development of advanced technologies. And we actually included $75 billion for advanced energy technologies in that bill as well.

But the fact is that we are already in the middle of the clean energy revolution. In 2005, the United States installed just 79 megawatts of solar across the entire Country. Last year we installed nearly 200 times that amount, 14,000 megawatts. We now have more than 40,000 megawatts of solar in the United States. We have more than 80,000 megawatts of wind capacity installed in the United States, including 8,200 new megawatts installed last year. On reliability, in Iowa, they are now producing, many days, 40 percent of all of their electricity from wind; it was very good reliability. So obviously tremendous breakthroughs have been made on that front. And a little more than a decade ago wind and solar generated less than 1 percent of all of our electricity. It is now 7 to 8 percent of all of our electricity. And if it continues at the existing pace, no further breakthroughs, it would be 30 percent of all of our electricity by the year 2030.

So that is the good news. There is a tremendous revolution that is taking place, and that is without any breakthroughs in

advanced wind or solar technology.

Today there are 360,000 Americans employed in the wind and solar industries. By 2020 there will be 500,000. And here is a number that is absolutely astounding: last year, the solar industry created as many jobs in one year as exists in the entire coal mining industry, 50,000 new jobs. So that is a huge, huge development. And they are good paying jobs. We have blue collar workers, 137,000 electricians and roofers were working last year in the solar industry in our Country. Just absolutely an incredible revolution, a blue collar energy job creation revolution that has taken place.

The same thing is true over on the wind side of these issues. We have 102,000 people working in wind; 25,000 of them are in manufacturing, 35,000 of them are in construction, transportation, and sales. There are 10,000 wind engineers just maintaining those devices across the Country, with a starting salary of $50,000 in our Country.

So there is a tremendous revolution that has absolutely been unleashed.

Dr. Bohlen, you included a chart in your written testimony showing how carbon capture and sequestration compares to other technologies in terms of unsubsidized costs. The chart shows onshore wind electricity has an all-in cost of as little as $32 per megawatt hour and solar has an all-in cost of as little as

$46 per megawatt hour. Electricity generated from natural gas with carbon capture, the cheapest CCS option costs more than $69 per megawatt hour, while electricity generated from coal with CCS costs more than $80 per megawatt hour.

That is why, in my opinion, utility executives are looking more towards alternatives. Could you talk about that in terms of how the free market is actually moving utility executive decisions towards cleaner energy sources and the lower costs, which increasingly are in the renewable sector?

Mr. Bohlen. Yes, Senator. First of all, I want to emphasize I am a scientist, not an economist, and the figures that I quoted were from an analysis by those who are expert in that, Lazard. But others do it, too.

What is clear is that costs are rapidly declining. And an important role that the national labs play in that is that they help de-risk the very, very early stage technologies and then bring the risks down through a variety of approaches; new materials, new manufacturing approaches, and modeling and simulation that greatly reduce the risk and make these new technologies viable in the commercial sector.

For example, the natural gas revolution in this Country was founded on $200 million of Federal investment, and that led to industry being able to take that over. I know George Mitchell, from Mitchell Energy, likes to talk about the role of industry.

But it was preceded by some significant Federal investment in hydraulic fracturing and wells, long horizontals.

So costs are coming down. Natural gas is less expensive per kilowatt hour, in general, than are other technologies; wind is less expensive, and so forth. So the economics are driving this and decisions by power companies.

Senator Markey. May I continue for just one more question, please, Madam Chair?

Senator Capito. One more.

Senator Markey. Okay, thank you, Madam Chair.

Senator Whitehouse and I have introduced legislation to extend the tax credits for offshore wind through 2025. The entire tax break expires for wind at the end of 2019. And offshore wind is clearly a huge potential job creation opportunity with very low greenhouse gas, non-existing greenhouse gas production. Could you talk a little bit about that, the offshore wind revolution, and what you think that might portend for the future, as well, and the kind of focus that we should have upon that as well, Mr. Bohlen, if you could?

Mr. Bohlen. Without moving into the policy issues, Senator, what I can say is we have examples around the world where offshore wind has been incredibly impactful. Denmark, for example, has very, very significant offshore wind, and they are moving towards powering their entire country in that way. So

the answer is there is enormous potential, and how that develops will be a matter of State policies and so forth.

Senator Markey. From my perspective, the same winds that brought the pilgrims to Massachusetts can also power our industry and our homes. The winds, as they have been mapped by the Department of Interior, indicate that off of our coastline is the Saudi Arabia of wind. So to the extent to which there is a movement towards new generations of electrical generation capacity, I think that wind has to be solidly in that category, and any tax breaks, any incentives that are created should include them as well, because the potential is vast.

Thank you, Madam Chair.

Senator Capito. Thank you. Thank you very much.

I can't help it, I have to say in terms of wind and Massachusetts, remember, we have to site the windmills, and, as I recall, over the last several years that has been quite a controversial thing off the coast.

I would like to --

Senator Markey. If I may.

Senator Capito. No, I am going to go on. I gave you some extra time. I am allowed to make a comment here.

On solar, let's talk about solar, because my understanding is that to manufacture solar efficiently, you need to have rare earth metals. I think was it Dr. Khaleel, did you mention, or

maybe Dr. Anderson, the rare earth? Are we are doing some of this at WVU? Could you talk about that a lot? Because I think that would help solar, that would help coal, and that would help the areas of coal ash and other residuals where these rare earth minerals can be found.

Mr. Anderson. Excuse me, Senator. Currently in the U.S., we import the vast majority, almost 100 percent, of our rare earth elements, and we do have some closed amount at the Mountain Pass Mine at the border of California and Nevada has a significant amount of light rare earth. However, what we found in the acid mine drainage sludge in the central and northern Appalachian coal fields is that we have a concentration of heavy rare earth elements, and we have been working on and developed a technology at WVU to be able to extract those heavy rare earths from the acid mine drainage sludge, so going out to remediated coal sites and extracting the rare earths that go into heavy permanent magnets that support the wind industry, as well as the materials for the construction of solar panels.

Senator Capito. And for those things we call cell phones, as well.

Mr. Anderson. Absolutely.

Senator Capito. Right.

Yes, Dr. Khaleel, did you want to add to that?

Mr. Khaleel. Yes, Senator. So, you know, as the Senator

earlier mentioned, there is an institute called the Critical Materials Institute, jointly done by multiple national labs, including Oak Ridge, and the objective is really to look at how we separate these elements from, say, you know, coal or other materials.

Rare earth elements are very critical for various applications, and the underpinning technologies are really separation technologies, so you need it for solar, you need it for magnets, for lighting, for multiple applications.

And the national labs, broadly speaking, have capabilities in separation that can be applied to these problems and also, you know, really help us in not relying on foreign sources for these elements.

Senator Capito. I think that is a great distinction on the security issue. If, all of a sudden, the supply dried up, that would cause great difficulties, I think, across many industries in this Country.

Let me ask you just a more global question because I have you all here. We have the Lawrence Livermore National Lab, we have the Oak Ridge National Lab, and Idaho National Laboratory. I hope I know the answer to this question because we are talking about some of the same technologies, whether it is nuclear or clean coal or carbon capture. Do you all have a regular coordination where you are coordinating your research working

together? I am assuming this is not the first time you have met. What kinds of efficiencies of scales? We are doing a lot at the National Energy Technology Lab in Morgantown as well.

Who wants to step up to that question?

Mr. Bohlen. It is interesting that question comes, Senator, as our chief research officers of all of the laboratories meet here today for a two-day meeting. They meet regularly. We work across the laboratory system very, very effectively. Yes, we compete. Yes, we think we have great technologies. But we also partner much more vigorously than people know because we just work together and get stuff done.

Senator Capito. Dr. Khaleel?

Mr. Khaleel. Senator, the DOE Office of Science has looked at all of the national labs and looked at their core capabilities, and based on critical mass in terms of the staff, critical mass in terms of facilities and equipment, the labs are assigned core capabilities. So in multiple areas you see some labs have the same core capability and they coordinate.

I think like Steve mentioned, we have also the national lab directors, you know, tomorrow meeting together. We also have bilateral work between the national labs. For example, we coordinate with the National Renewable Energy Lab. They are the renewable energy lab and we do a lot of work in energy efficiency. So we have a lot of complimentary capabilities.

For example, the Senator talked about offshore wind. One of the basic and fundamental capabilities, really advanced manufacturing, especially of composite materials. We use, at Oak Ridge, 3-D printing to enable that to happen, and we work with IRNL. Likewise, we coordinate with Idaho National Lab in the area of nuclear.

So you see a lot of these partnerships to leverage facilities and staff and capabilities.

Senator Capito. Dr. K, did you have a comment on that?

Mr. Pasamehmetoglu. Yes. I will comment on the nuclear piece.

As I indicated before, the nuclear research capabilities are expensive and they are not all located in one place, so they are spread across the DOE complex and multiple national laboratories. So just by virtue of that we have to collaborate and we have to complement each other, and the recent vehicle -- yes, in the past there was competition, but the recent vehicle for that collaboration has been that initiative that I mentioned, the GAIN Initiative, that basically ties the laboratories together.

Senator Capito. Thank you.

Senator Carper.

Senator Carper. Thank you.

Folks, just to refresh your memories, I had asked a

question about the role of the Federal Government with respect to clean energy technologies, and I had asked how important has the Federal Government's role been in the last decade or so in providing a nurturing environment for clean energy investments and job creation related to those. And then I asked what more can the Federal Government be doing or should be doing in this regard, and we got as far as you, Mr. Bohlen.

If you could just take a shot at that. Not too long, but just take a shot at that for me. What more could we be doing, should we be doing in this vein?

Mr. Bohlen. Yes, Senator. What we know from looking at experience is that investment in these technologies at the national laboratories, with their university partners and industry partners, lowers the risk and lowers the costs so that they become commercially competitive. So in the wisdom of the Congress and the Federal investment apparatus, whatever they want to invest in, they know they will get lower risks and more rapid commercialization by investing. This has been demonstrated over and over and over again.

Senator Carper. Thank you very much.

Dr. Khaleel, also known as Moe?

Mr. Khaleel. The first thing is for the Government to have stronger support for the national user facilities, the science user facilities and the applied program user facilities, as

these facilities attract elite scientists from universities and industry to work on challenging problems with the talent at the national labs. I think that is fairly important.

The other thing is really to have more focus on early stage R&D, but also mid-stage and later stage, and to open the national lab as we are doing it today, but more deliberate to work with the industry, the U.S. industry, to help them in buying down some of the risk, especially as we have the best capabilities to deal with early-stage and mid-stage R&D.

Senator Carper. All right, thank you.

I also want to ask Mr. Pasamehmetoglu. I know that wasn't very well done, but I just wanted to stay here to try to pronounce your name. Do you have any nicknames? What do your friends call you?

Mr. Pasamehmetoglu. Well, my friends call me Kemal.

Senator Carper. All right. All right, Kemal it is. Take it away. Same question. What more could we be doing, should we be doing?

Mr. Pasamehmetoglu. Well, I think the issue we need to look at, if you are really serious to take over, to at least maintain the technology leadership and regain the industrial leadership in nuclear energy, and especially in the advanced nuclear systems, I think it is important as a Nation for us to look at a different way of public-private partnership because a

lot of these technologies have large promises to cut cost and to be a lot more efficient; however, jumping over the hump of a first-of-a-kind unit is not something that the private sector alone can do. So, in my opinion, a new model of public-private partnership to get us through that initial hump and get those things to end of a kind where they are economically competitive, and then the private sector can take over and run with it.

Senator Carper. I want to go back, before I conclude, to where I started, and that was to talk about the visit of Secretary of Agriculture, Sonny Perdue, former governor of Georgia, to Delaware yesterday, and it was a wonderful, wonderful visit that focused on what we are doing in our ag economy and how we can strengthen it further. And I mentioned the one farmer who talked about what the effect of climate change is having on his livelihood, and he was very concerned about it.

Delaware is the lowest lying State in America, and we see the vestiges of sea level rise every day. We had huge storms in the last couple days, but even throughout the year we see vestiges of what is happening to our coastline and to our State, and we are not the only State.

The work that you all are doing, and your colleagues are doing, is just enormously important as we deal with what is a reality for us. I have always looked at adversity and tried to

find opportunity in that adversity. That is Einstein. And I think there is a chance for us to draw on that again in this vein as well, to look at adversity, too much CO2 in our air, find opportunity.

Thank you for helping us find it.

Senator Capito. Senator Markey, second round, five minutes.

Senator Markey. Okay. Thank you, Madam Chair.

Boston is the fourth most vulnerable city in the United States to climate change, and it is the eighth most vulnerable city in the world in terms of economic impact, so we are very conscious about this issue; it has tremendous implications for our well-being.

Just coming back to the colloquy that I was having with the Chairwoman earlier, there was a problem with the siting process for wind off of the coast of Massachusetts, but what has happened now is that pursuant to the 2005 Energy Act, although the Bush Administration did not act on it, they should have, the Department of Interior has now mapped off of the coast of Massachusetts, in our federal waters, where it is acceptable to deploy wind. And the State of Massachusetts has now established its goal of deploying 1,600 megawatts of offshore wind over the next 10 years. And now New York is following and the Department of Interior is continuing its mapping off of the coast in

federal waters that gives more certainty, economically, to the development of wind technology.

So the objective should be, from my perspective, to ensure that there is a level playing field as we are going forward. Yes, we need to help with carbon capture and sequestration. Yes, we need to look at the Nuclear Regulatory Commission and its regulations. But we also have to make sure that the barriers to entry for offshore wind or for the continuing development of solar are also taken into account so that it is a race. And as we know right now, this race does have wind and solar now sprinting out towards a minimum of 30 percent of all electrical generation.

And, by the way, if you add in the 6 percent of all electrical generation, which is hydro, by the year 2030, because that will not change, and potentially keeping nuclear at around 19 percent, we are looking at 55 percent, 56 percent of all electricity being non-greenhouse gas emitting within 13 years in our Country, and that is if wind and solar and other renewable technologies don't make any additional breakthroughs, if we don't have breakthroughs in battery technologies that can contribute to the reliability of using renewables in our national grid. And I would bet on a breakthrough in battery technology because of the vast fortune to whichever individual or company makes that breakthrough. They could ultimately

become the wealthiest company on the planet. So there is a huge economic incentive to make that breakthrough as well.

So I am just basically somebody that wants an all-of-the-above strategy, truly an all-of-the-above, and it includes carbon capture and sequestration for our fossil fuel industry, but also extending the tax breaks for wind and solar, ensuring that the continued mapping of the coastline continues, because that could come into jeopardy in a Trump era Department of Interior. But as long as that is in place, then I think we are going to be on a pathway to solve the problem.

So I thank you, Madam Chair, and I thank you for holding this very important hearing.

Senator Capito. Thank you.

I want to thank the witnesses, and I would like to note that the record for the Committee will stay open for two weeks, and I would ask the witnesses that any written questions that were submitted to you, if you could respond in a timely fashion, it would be much appreciated.

Thank you all for coming.

[Whereupon, at 11:50 a.m. the committee was adjourned.]