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DEVELOPING AND DEPLOYING ADVANCED CLEAN ENERGY TECHNOLOGIES

HEARING

BEFORE THE

SUBCOMMITTEE ON CLEAN AIR AND NUCLEAR SAFETY

OF THE

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS UNITED STATES SENATE

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

JULY 25, 2017

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ONE HUNDRED FIFTEENTH CONGRESS
FIRST SESSION

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HEARING ON DEVELOPING AND DEPLOYING ADVANCED CLEAN ENERGY TECHNOLOGIES

TUESDAY, JULY 25, 2017

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

The committee met, pursuant to notice, at 10:07 a.m. in room 406, Dirksen Senate Office Building, Hon. 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.

OPENING STATEMENT OF HON. SHELLEY MOORE CAPITO, U.S. 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 dialog from our members.

I will now yield and welcome our Ranking Member, Senator Whitehouse, for his 5-minute opening statement.

OPENING STATEMENT OF HON. SHELDON WHITEHOUSE, U.S. 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.

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.

OPENING STATEMENT OF HON. LAMAR ALEXANDER, U.S. 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 5 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:]

PREPARED STATEMENT OF HON. LAMAR ALEXANDER, U.S. SENATOR FROM THE STATE OF TENNESSEE

Thank you Chairman Capito and Ranking Member Whitehouse for inviting me today and for holding this hearing. And, thank you to the witnesses for being here today. Today, our country has 99 nuclear reactors. These 99 reactors are capable of producing 100,000 megawatts of clean, reliable electricity—with zero carbon emissions. If we were to close those 99 nuclear reactors, which provide more than 60 percent of our 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 our roads.

That's more than all U.S. passenger cars on the road today. If you are concerned about climate change, that possibility is alarming. And while we normally think of clean nuclear power when we are talking about climate change, it's much more fundamental than that. First, it's about jobs. The nuclear industry employs 100,000 people throughout the country. These are high-quality, good-paying, career-long jobs. In South Carolina and Georgia, the four nuclear reactors currently under construction created about 10,000 jobs. If you're concerned about unemployment and the communities that support our existing nuclear reactor sites, the thought of losing these jobs is alarming.

Second, it's about reliable electricity. Nuclear reactors operate over 90 percent of the time and provide reliable, baseload power. We all rely on electricity every day. We expect our lights to turn on in the morning and our air conditioners to work in the evenings. 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 power, none of this would be possible. If you're concerned about domestic manufacturing and supporting the 12.3 million manufacturing workers in the United States, losing 100,000 megawatts of baseload power is alarming.

Third, it's about affordable electricity. While natural gas prices are low today, less than 10 years ago, natural gas prices in the United States 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 United States we have today lowers the cost of generating electricity by more than $93 billion per year. This means having nuclear, coal, hydropower, and natural gas all available lowers the cost of electricity. Losing this diversity could be very costly. So if you're concerned about providing low-cost power in the United States, losing nuclear power—which supplies 20 percent of our nation's electricity—is alarming.

I think it's clear that we must do something to support nuclear power. But, over the last 5 years, six nuclear reactors have shut down prematurely and analysists have warned dozens of additional nuclear reactors could potentially shut down over the next 10 years. And in roughly two decades, the United States could lose about half of its reactors. That's because, by 2038, 50 reactors will be at least 60 years old, which is when their licenses run out, representing nearly half of the nuclear generating capacity in the United States. We could replace that lost generation with natural gas. But that could lead to an increase in electricity prices and increased carbon emissions. Or we could replace that lost generation with renewables. But that would lead to a considerable loss in reliability and could lead to a large increase in electricity prices. And 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 reactor fleet.

The way I see it, we must replace that lost generation with new nuclear reactors. And to do that we must develop the next generation of nuclear reactors. We must continue to develop and be ready to efficiently license small modular reactors and advanced reactors. These new technologies could represent the future of nuclear power. These new reactors will be safer, produce less waste and operate with higher efficiencies and at a lower cost than the existing reactor fleet while still providing carbon-free electricity. But, our next generation of nuclear reactors will likely not be possible without government funded research and support. Which means we must double funding for basic energy research.

I think the best way to lower the cost of energy, clean the air, improve health, increase family incomes, and produce good-paying jobs is to double funding for basic energy research and drive American innovation. We must continue to support the good work our national laboratories are doing on advanced reactors. Dr. Moe Khaleel is here today to talk about the great work they're doing at the Oak Ridge National Laboratory in Tennessee. Dr. Khaleel is the Associate Lab Director for Energy and Environmental Sciences at Oak Ridge. In his role, Dr. Khaleel oversees the lab's activities that bring basic science to applied research and development to support energy production, transmission, and conservation. I thank the Chair and Ranking Member for inviting me to this hearing and look forward to the testimony from the witnesses and hearing about what we can do to advance the next generation of nuclear reactors.

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 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:]

The New Nuclear Renaissance

The future of nuclear energy in the U.S. is bright

By Jim Inhofe, Sheldon Whitehouse, Mike Crapo and Cory Booker
July 11, 2016, at 11:35 a.m.

There has been a groundswell of activity and investment in recent years surrounding advanced nuclear reactors. A dynamic group of nuclear engineers and scientists are chasing the future – and racing against China and Russia – to develop innovative reactor designs. These technologies hold enormous promise to provide clean, safe, affordable, and reliable energy, not just for our country, but for the world. These innovators have a vision for the future, and they charge ahead backed by more than $1 billion in private capital. The future of nuclear energy is bright.

Some would argue that we have been here before. In 2005, Congress passed incentives to encourage a "nuclear renaissance" amid high natural gas prices. The industry stood ready to build a large number of modern light-water reactors, improved versions of existing nuclear technology.

But reality fell short of expectations and the result was only five new nuclear plants, with a price tag of $8 billion to $10 billion each. Now, in an age of low-cost natural gas, it is becoming harder for the nearly 100 existing reactors to compete. The Energy Information Administration calculates that electricity generation from a new nuclear plant would cost about 25 percent more than electricity from a new gas-fired combined-cycle power plant. This is causing some nuclear energy companies to scale back their operations. For instance, Chicago-based Exelon Corporation announced just a few weeks ago that it would shutter two of its nuclear plants in Illinois in the coming years, citing pressure from natural gas as a major factor.

So this begs the question: Will this new wave of innovative reactors live up to its promise? Investors think so, and so do we. For starters, these advanced reactors differ significantly from their predecessors. Rather than water, they use materials like molten salt or noble gasses as coolants. Most are considered "walk away safe," since they are designed to use the laws of physics, rather than equipment, to prevent accidents. If a natural disaster strikes, for instance, these reactors would simply shut down, substantially reducing the threat of a meltdown. Many are designed to be small and modular, so they could be built in factories with construction costs that are a fraction of their big, custom-built forerunners. Small reactors could also be plugged into future micro-grid systems without requiring extensive transmission infrastructure. Some of these new reactor technologies could actually help to reduce the amount of nuclear waste we've accumulated through the years by using that waste as fuel. That could alleviate a major challenge facing the industry. And of course, all of this would be achieved without any air pollution.

Nuclear energy used to be just another partisan issue. Thankfully, that is changing. The four of us represent opposite ends of the political spectrum in the Senate, but we are all pulling in the same direction, backing various pieces of legislation to promote advanced nuclear innovation and development. One bill would open the doors of our national laboratories to entrepreneurs and their innovative new companies to develop public-private partnerships with the potential to bring new ideas to market. Another bill looks to build a sensible regulatory framework to allow diverse advanced reactor concepts to go from the drawing board to reality.

These bills have been moving through Congress and are garnering broad bipartisan support. The Nuclear Energy Innovation Capabilities Act recently passed the Senate as part of a bipartisan energy bill, on an 87-4 vote. The Nuclear Energy Innovation and Modernization Act was approved by the Senate Environment and Public Works Committee on a 17-3 vote.
Though we may come to this issue for different reasons, our end goal is the same. We want to promote new technologies that provide cleaner energy and get them built by and for Americans. We can't take a back seat as China and Russia build test reactors and lure away American innovators. This new nuclear renaissance is primed for success. It has broad bipartisan support in Congress, serious private capital investment and the ability to help address environmental challenges – all while encouraging American innovation. The world is heading into a new age of nuclear energy, and the United States must lead the way.

Available at: https://www.usnews.com/opinion/articles/2016-07-11/americas-next-nuclear-power-renaissance-is-here

Jim Inhofe | CONTRIBUTOR

Jim Inhofe is a Republican senator from Oklahoma. He chairs the Committee on Environment and Public Works.

Sheldon Whitehouse | CONTRIBUTOR

Sheldon Whitehouse is a Democratic senator from Rhode Island.

Mike Crapo | CONTRIBUTOR

Mike Crapo is a Republican senator from Idaho.

Cory Booker | CONTRIBUTOR

Cory Booker is a Democratic senator from New Jersey.

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:]

The New York Times https://nyti.ms/2igUTZM

The Opinion Pages | OP-ED CONTRIBUTORS

To Slow Global Warming, We Need Nuclear Power

By LAMAR ALEXANDER and SHELDON WHITEHOUSE DEC. 21, 2016

If 20 fire marshals came around and told us our houses were about to burn down, we'd buy some fire insurance. So when the leading science academies in 20 developed countries, along with several major American corporations and the national security community, all tell us that burning fossil fuels is causing dangerous changes to the climate, we think it's time for the United States to get serious about clean energy. It also means supporting safely operating nuclear power plants that produce carbon-free electricity.

Already, 60 percent of our carbon-free electricity comes from the 99 nuclear reactors that dot the nation's map, from Avila Beach, Calif., to Seabrook, N.H. These reactors provide low-cost, reliable electricity for the United States, which uses nearly 20 percent of the world's electricity. But over the next decade, at least eight of these reactors are scheduled to shut down. That will push up carbon emissions from the American electricity sector by nearly 3 percent, according to the United States Energy Information Administration.

In California, the closing of the San Onofre Nuclear Generating Station in 2012 contributed to a 24 percent increase in carbon emissions from the electricity sector, according to data from the California Environmental Protection Agency Air Resources Board. Carbon emissions from the electricity sector in New England rose 5 percent in 2015, the first year-to-year increase since 2010, largely because of the closing of the Vermont Yankee Nuclear Power Station in December 2014, according to ISO New England, the region's grid operator.

In roughly two decades, the United States could lose about half its reactors. That's because, by 2038, 50 reactors will be at least 60 years old, and will face having to close, representing nearly half of the nuclear generating capacity in the United States. Without them, or enough new reactors to replace them, it will be much harder to reduce carbon emissions that contribute to climate change.

Unfortunately, some of our federal policies to encourage clean energy, such as the Clean Energy Incentive Program within President Obama's Clean Power Plan, do not explicitly include or incentivize nuclear power. Likewise, some states have chosen to adopt policies, such as renewable portfolio standards, that do not include or incentivize nuclear power.

At the same time, our energy markets do not currently account for the value of carbon-free power, a failure that puts nuclear power at an unfair and economically inefficient disadvantage to fossil fuels like coal and natural gas.

We come from different political parties, but we agree on the overall goal of leveling the playing field for nuclear power, and the need to find a bipartisan solution to achieve it. This matters because the investments we make today, in new plants and transmission infrastructure, will be around for decades. Every time new fossil energy replaces nuclear, we're locking ourselves in to a more carbon-heavy energy mix for years to come.

Some states and utilities are working to reduce carbon emissions with the understanding that nuclear power can be part of the solution. In the Southeast, there are four new reactors under construction that will provide 4,470 megawatts of carbon-free electricity — enough for 3.3 million homes. New York established a clean-energy standard in August that might help the state's reactors stay open, including one that had been announced as closing. Gov. Andrew M. Cuomo's office explained that "maintaining zero-emission nuclear power is a critical element to achieving New York's ambitious climate goals." And the private sector is pitching in, too: According to Energy Secretary Ernest J. Moniz, there are dozens of entrepreneurs focusing on ways to improve and expand the nuclear power industry.

The federal government should support these efforts.

For one thing, we should extend existing reactor licenses from 60 to 80 years, in cases where the Nuclear Regulatory Commission says it is safe to do so.

We should also invest more in research to develop advanced nuclear reactors, including small modular reactors and accident-tolerant fuels. Advanced reactor designs may substantially reduce the threat of a meltdown. Many new, modular designs are much smaller than their predecessors, meaning they can be built in factories at lower cost and plugged into the grid as needed.

Some of these new reactor technologies could actually use waste from traditional reactors as fuel, helping to alleviate a major challenge facing the industry. The Nuclear Regulatory Commission licensing framework, developed to support the last generation of reactors, should be updated to encourage and promote new investment in the next wave of advanced nuclear technology. And finally, we need to resolve the stalemate over where to store used nuclear reactor fuel.

If we want to clean the air and reduce carbon emissions to deal with climate change, we need a stronger, not weaker, nuclear energy sector. Congress, federal agencies and the Nuclear Regulatory Commission must work with utilities to preserve our existing reactors in the safest possible way, and to develop the next generation of reactors that will provide cheaper, reliable, carbon-free electricity.

Senator Lamar Alexander, Republican of Tennessee, is the chairman of the Senate Appropriations Subcommittee on Energy and Water Development. Senator Sheldon Whitehouse is a Democrat from Rhode Island.

A version of this op-ed appears in print on December 22, 2016, on Page A29 of the New York edition with the headline: To Save the Planet, Go Nuclear.

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 5 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 5-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 CO_2 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:]

Written Testimony of Brian J. Anderson to the Clean Air and Nuclear Safety Subcommittee
July 25, 2017

Chair Capito, Ranking Member Whitehouse and members of the Subcommittee, thank you for the opportunity to offer relevant testimony and to answer your questions in my areas of experience and expertise.

I am the Director of the WVU Energy Institute at West Virginia University in Morgantown, West Virginia. The WVU Energy Institute is the central organization on the West Virginia University campus with a mission to coordinate cross- and multi-disciplinary research across our 14 schools and colleges in energy as well as working with the state of West Virginia to stimulate economic development while utilizing our energy resources responsibly. In addition to my role as director, I am the GE Plastics Materials Engineering Professor of Chemical Engineering and have 17 years of energy research experience primarily in chemical engineering and in subsurface science as related to CO_2 sequestration, natural gas hydrates, unconventional gas production, and geothermal energy.

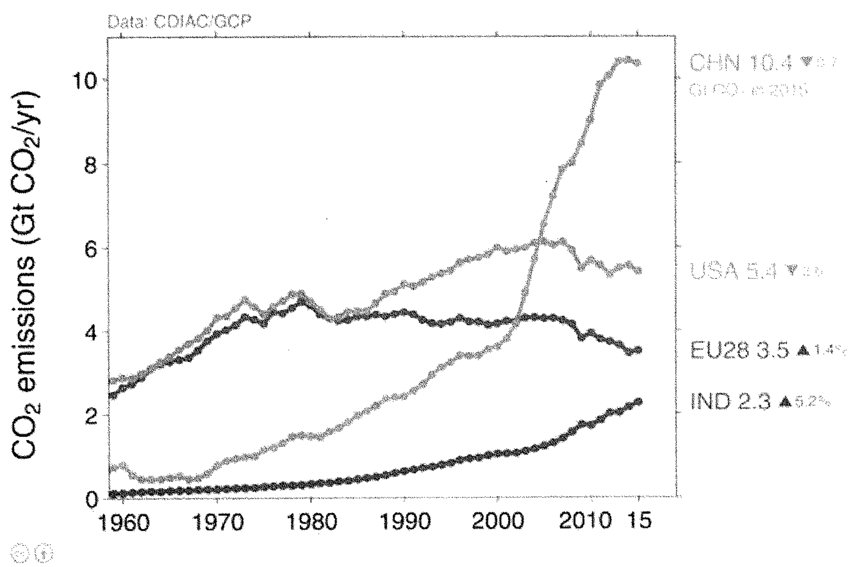
West Virginia University is a public, land-grant, research-intensive university founded in 1867. It is designated an "R1" Research University (Very High Research Activity) by the Carnegie Foundation for the Advancement of Teaching; funding for sponsored research programs exceeds $170 million. The Morgantown campus houses the West Virginia University Energy Institute, the National Research Center for Coal and Energy, and the Center for Alternative Fuels, Engines and Emissions which discovered the Volkswagen diesel engine emissions software installation that allowed its diesel engines, in test mode, to meet emissions compliance standards, but to operate out of compliance when not in test mode.

The university has active and ongoing research related to operating improvements on existing coal-fired power generation, the recovery of rare earth elements from coal wastes, instrumentation and sensor development to accurately measure fugitive emissions from shale gas wells, analysis of sub-surface geological structures and their applicability to store gas liquids, store carbon or produce gas. The university also has developed sophisticated software and algorithms that can model complex fossil fuel combustion systems, as well as complex electric transmission grids responding to variable generation from intermittent sources like solar and wind.

Additionally, the U.S.-China Clean Energy Research Center Advanced Coal Technology Consortium is based in the WVU Energy Institute at West Virginia University in Morgantown, West Virginia. The consortium is one of five consortia that were created through a bi-lateral Protocol signed in 2009 between the United States Department of Energy and two agencies of the People's Republic of China: the Ministry of Science and Technology and the National Energy Administration. The initial phase of Center's Protocol spanned five years (2011-2015) and in 2015 was extended an additional five years (2016-2020) under the direction of Jim Wood. From 2009 to 2012, Jim was the Deputy Assistant Secretary for what is now called the Office of Clean Coal and Carbon Management in the U.S. Department of Energy's Office of Fossil Energy. He was responsible for the agency's coal research program and the large demonstration projects co-funded with industry under the third round of the Clean Coal Power Initiative, including funds added from the American Recovery and Reinvestment Act of 2009.

The United States is blessed with an abundance of diverse electric generation sources. Diverse sources of generation improve transmission grid operation, moderate retail electricity costs, and reduce unhealthy emissions levels. The benefits of diversity are not unlike the mitigation of risk from diversity in savings and investment portfolios. Research into carbon emissions reduction is an important strategy to preserve the diversification of generation enjoyed by the United States. Although both the rate of carbon emissions growth, and its emissions in absolute numbers have begun to decline, much of this is due to substitution of lower carbon emitting generation for coal-based generation. Part of this also is due to the reduced growth of GDP over the last decade and one could expect this decline to slow, and possibly reverse, when U.S. GDP growth rates increase. Having economic and commercial technologies to capture, reuse or permanently store carbon before its emissions are atmospheric, should be part of strategies to maintain the diversification of generation, and indeed provide economic benefits when these technologies are exported.

Many parts of the world are not equally blessed with diverse generation, and to a larger extent must rely on inexpensive local fuel sources high in carbon and resulting carbon emissions. Among these are the two most populous countries in the world, China and India. In the 2000 World Energy Outlook, the International Energy Agency estimated China's emissions would be 18% of the global total in 2020. In 2015 the actual value was 29%. Recently Chinese President Xi Jinping announced China's carbon emissions would peak in 2030.



West Virginia University's research activities help support diverse, low-carbon generation in many ways:

1. Models of complex combustion systems that burn fossil fuels in pure oxygen in order to explore the thermodynamic properties of flame development, which is a precursor to designing pilot and demonstration combustors with carbon capture and efficient heat transfer properties;
2. Models of complex combustion systems that burn fossil fuels in vessels containing inexpensive oxidants, like iron oxide, or aluminum oxide, that can be used to develop technical solutions for combustion without air, which may generate pure dense phase CO_2, ready to transport to a storage repository, or for reuse;
3. Models of complex electric transmission systems that must maintain voltage, frequency and capacitance stability when multiple sources of diverse generation are competing to supply a demand curve that does not match the intermittent properties of the diverse sources of generation;
4. Down-well sensors and technologies, including innovative fiber optic and micro seismic sensors, that better describe formation performance during formation stimulation and drilling, including gas production flow paths and flow paths of stimulation fluids and proppants that improve safety and well bore efficiency;
5. Above-well sensors that detect even small releases of greenhouse gasses during stimulation, drilling or production operations of shale gas wells;
6. Chemical reaction research that improves gas and gas liquids conversion processes, improves efficiency, and reduces fugitive emissions;
7. Rare earth element extraction processes and strategies from U.S. coal mine wastes, and potentially combustion ash, that are critically important for U.S. defense and industrial uses and that are found now in, and often controlled by, other countries;
8. Analysis and measurement of pipeline fugitive emissions, and control strategies that minimize those emissions;
9. Research into technical and economic advances of renewable geothermal sources of energy;
10. WVU also is leading a tri state (WV, PA, OH) effort to undertake rigorous sub-surface analyses of proposed Appalachian Storage Hub locations for gas liquids that will greatly reduce fugitive emissions of shale gas produced in Appalachia as compared to emissions released if that gas was transported to hubs south or east of Appalachia.

West Virginia University's role in managing the U.S.-China Clean Energy Research Center Advanced Coal Technology Consortium gives the university good visibility into China's research and development on solutions to carbon emissions. Consortium members include the University of Wyoming, the University of Kentucky, Washington University (St. Louis), National Energy Technology Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, the World Resources Institute, Alstom (now GE) Power, Arch Coal, Duke Energy, the Electric Power Research Institute, the Gas Technologies Institute, Jupiter Oxygen Corporation, LP Amina LLC, Peabody Energy, the Southern Company, and Stock Equipment Company. Research undertaken by the consortium includes advanced combustion technologies, including chemical looping and pressurized oxy-combustion of coal, pre- and post-combustion carbon capture technologies and techniques, including micro-algae absorption of CO_2, and advances in carbon conversion technologies.

In the seven years subsequent to the Protocol signing ceremony, a number of important relationships have developed between U.S. and China consortium members. West Virginia University has ongoing collaborations with the Shenhua Group Ltd. (the largest coal producer in the world), and Shaanxi Yanchang

Petroleum Company Ltd. There is evidence through these, as well as other business and academic relationships that China depends on coal for approximately 85% of its energy needs. About 50% of its coal consumption is used in the generation of electricity. The balance is used to derive chemicals, and liquid fuels from coal. China's dependence on coal should not be underestimated, nor should effects of the lack of generation diversity on its transmission grid. Consequently, China has made large commitments and investments into cleaner utilization of coal and particularly criteria and climate change emissions reductions. The chart below compares China's current regulations for criteria emissions with those of the U.S. and EU. The *, **, *** notations refer to location- relevant (usually Provincial) limits now overridden by the lower National Limits:

TABLE 1

Coal-fired power emission standards in China, the United States, and the European Union

Conventional air pollution standards for new and existing power plants, in milligrams per cubic meter (mg/m3)

		China	United States	European Union
Nitrogen oxide	Existing	100*	135	200
	New	50	95	150
Sulfur oxide	Existing	50/100/200**	185	200
	New	35	136	150
Particulate matter	Existing	20/30***	19	20
	New	10	12	10

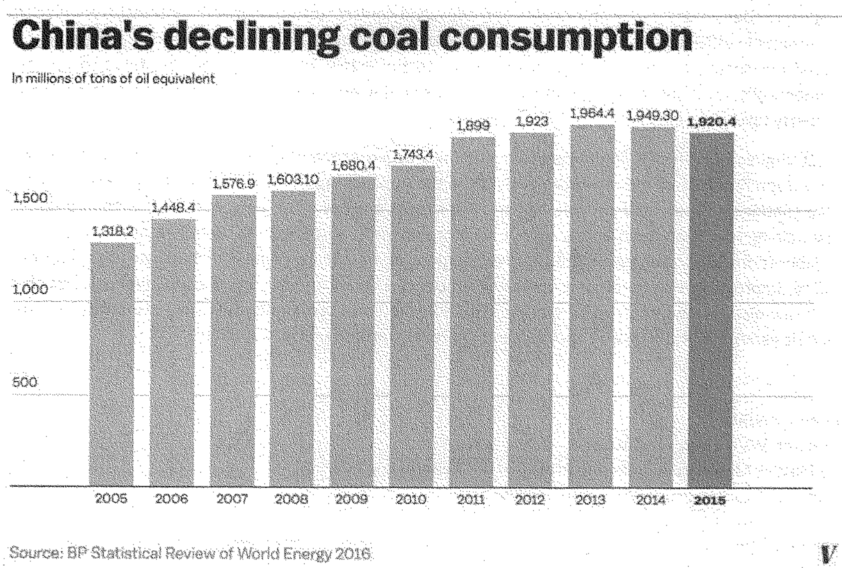
https://www.vox.com/energy-and-environment/2017/5/15/15634538/china-coal-cleaner

https://www.americanprogress.org/issues/green/reports/2017/05/15/432141/everything-think-know-coal-china-wrong/

China is an observant partner; it studies decisions other countries have made, and the consequences, of those decisions. It appears that China's principal choice to reduce emissions from coal-fired electrical generation is efficiency increases to its coal-fired fleet. China's most efficient coal-fired plant is the 1000 MW Guodian Taizhou plant which operates at about 45% thermal efficiency (http://www.powermag.com/who-has-the-worlds-most-efficient-coal-power-plant-fleet/).

By comparison, the most efficient coal-fired plant in the U.S. is the privately-owned Longview Power LLC which operates at about 40% thermal efficiency. There is evidence that China's consumption of coal is declining. Some attribute this to an increase in renewable energy. While China is installing as much renewable energy as possible, it also has 36 nuclear power plants in operation, 21 under construction and plans to have 150 Gw, or approximately ten percent of its electric generation, in operation by 2030 (http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx).

China also is decommissioning its old, low efficiency coal fleet and replacing it with high efficiency, low emissions power fueled with indigenous coal. For every megawatt of old coal capacity China replaces with new coal capacity, its criteria and carbon emissions decline 10% on a per unit of electricity generation basis. So does its coal consumption.



The low generation costs from renewable and gas-based electricity are putting pressure on the U.S. coal-fired base-load fleet principally because it operates, on average, at 32% thermal efficiency. Most of the operating capacity has been retrofit with criteria emissions controls, and is well-maintained. However, because these units are called into service later in the daily dispatch cycle, they often operate below full load, and undergo frequent pressure and temperature cycles that were not accounted for in those plant designs when they were constructed. Operation at reduced load also reduces a plant's thermal efficiency, which increases its carbon footprint.

Since 2011, roughly 350 coal-fired generating units have shut down according to the Energy Information Agency (https://www.wsj.com/articles/coals-decline-spreads-far-beyond-appalachia-1497870003).

When an owner determines a plant is no longer viable it is mothballed, and ceases to be maintained. The rotating equipment, electrical and controls systems decay rapidly. A similar issue faces the U.S. nuclear fleet which is not a carbon emitter. In both cases diversity of generation is reduced, investors or customers have expensive stranded assets to deal with, jobs are lost, and local property tax revenues decline, often with serious economic consequences to host communities.

There may be gigawatts of operating coal-fired generation that under some circumstances could be upgraded with technologies that would improve operating efficiency and reduce emissions, thereby allowing those units to compete for more operating hours and minimize the effects of cyclic operation. Some of these technologies could include conversion from coal to natural gas, replacing old turbine blades, condenser and feedwater heater upgrades, and control system upgrades. Interest from electric generators in efficiency improvements could benefit research centers and U.S. vendors that have largely exited this sector, or moved operations to Asia. To the extent these units then continue to operate economically, local host communities will continue to enjoy economic benefits associated with jobs and property taxes.

West Virginia University is committed to maintaining active, outcomes-based research that will improve the carbon footprint of the resources available in the Appalachian Basin so that industry and commerce may continue to grow and provide opportunities to its citizens. The university also is committed to maintaining robust business and academic relationships with partners in Europe, and Asia. Trans-global collaborations like these accelerate the development of electric generation technologies that improve safety, improve maintenance and operating efficiencies, and promote adoption of technologies that control emissions and improve air quality. This helps regional economic expansion, promotes low cost electric generation from diverse sources, and improves transmission grid stability.

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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 CO_2 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 CO_2 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 CO_2 as a frozen solid. Early tests have shown a 99 percent CO_2 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 CO_2 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 CO_2 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 CO_2 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 U.N. 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:]

Written Testimony Submitted to the United States Senate Committee on Environment and Public Works Subcommittee on Clean Air and Nuclear Safety

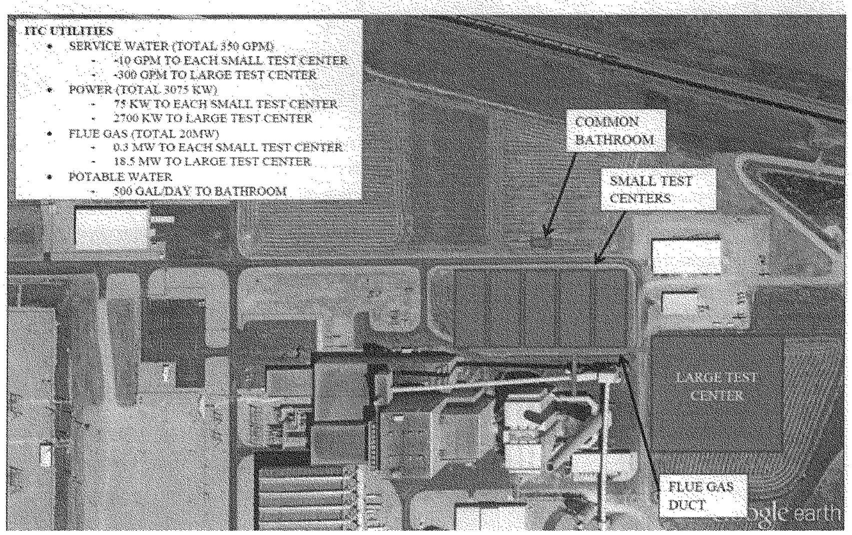
Testimony on Developing and Deploying Advanced Clean Energy Technologies

Submitted by Jason Begger, Executive Director, Wyoming Infrastructure Authority, July 25, 2017

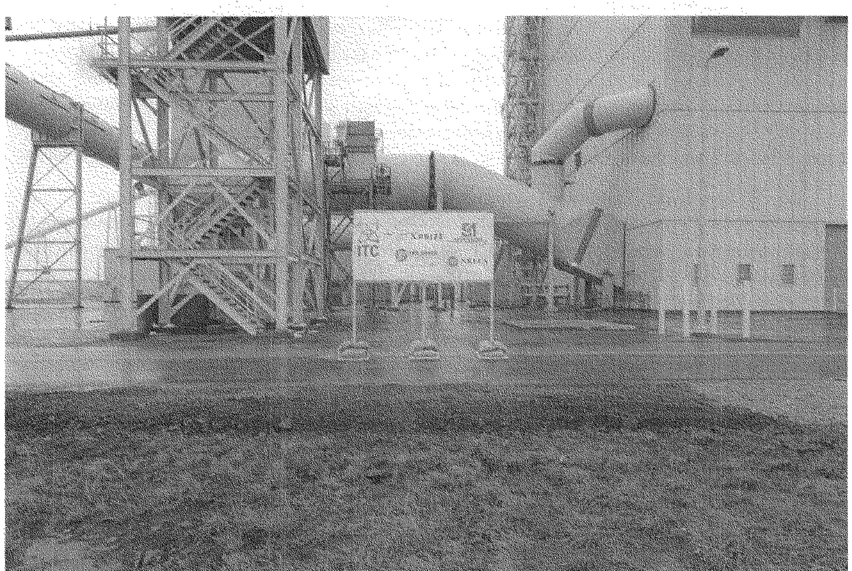
Madam Chairman, members of the Subcommittee, I appreciate the opportunity to speak to you today about our carbon technology efforts in Wyoming. My name is Jason Begger and I am the Executive Director of the Wyoming Infrastructure Authority. The WIA is a state instrumentality created by the Wyoming Legislature in 2004 to promote and assist in the development of energy infrastructure. Under our legislative authority, we work to construct electrical transmission lines, advanced generation facilities and coal export terminals. We also have the ability to issue up to $1 billion in industrial revenue bonds to assist with project financing.

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 Transmission and Generation Association and the National Rural Electric Cooperatives Association (NRECA). We have also received various in-kind contributions from Black Hills Energy and Rocky Mountain Power.

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



We have raised $21 million in funding, $15 million from the State of Wyoming, $5 million from Tri-State G&T, and $1 million from NRECA. $14.9 million has been budgeted for capital construction and approximately $900,000 for annual operating costs, providing us with the resources to construct and operate the ITC for 7 years. While we believe there is an important role for the Federal Government to play in advancing technology and we would welcome such a partnership, not one cent of federal funding has been utilized at the ITC.



The State of Wyoming is the nation's largest coal producer, producing approximately 300 million tons in 2016. While this is still a significant amount of production, it is down from the peak in 2008 of 480 million tons, a drop of 37.5%. Coupled with similar drops in crude oil and natural gas prices and production, Wyoming has experienced significant reductions in tax revenues.

Given fossil energy's prominent role in the state, investment in carbon control technologies by Wyoming may seem unusual, but it all stems from Governor Matt Mead's directive to move beyond the political rhetoric surrounding climate change science and focus on discovering technology solutions to ensure the long-term economic viability of Wyoming's fossil energy resources. The ITC is just one of a number of Wyoming programs aimed at commercializing next generation coal technologies. The University of Wyoming School of Energy Resources works on small scale, academic research; the Wyoming Pipeline Initiative is working to pre-permit corridors for CO2 pipelines; the Wyoming Enhanced Oil Recovery Institute researches the reservoir geology and is identifying carbon sinks for EOR opportunities and the Carbon Management Institute has active grants with the Department of Energy to study permanent geologic sequestration.

The one constant variable for all of these state entities is a push to commercialization. Every project needs to continuously track costs and economics, because without a demonstrable path to commercialization, all you have is an interesting idea. Strong partnerships with the private sector, especially those industries that would ultimately be a customer of the technology, helps ensure our research objectives are aligned with their economic needs. A great example of how this has been successful for Wyoming is the ITC Technical Advisory Committee. This committee is comprised of representatives from major utilities who are involved in the technology evaluation processes for their various companies. If a utility does not see a particular technology as something they would employ, it is not given priority.

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

One technology that has received support from Wyoming is cryogenic Carbon Capture. The various components in 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% CO2 capture rate, costing less than $30/ton and less than a 15% parasitic load. This method has also proven to be very successful at removing sulfur dioxide, nitrous oxide and mercury. While we've seen promising results at a small scale, further funding is necessary to test this as a larger pilot project.

One of the most exciting partnerships we've developed is with the XPRIZE Foundation. XPRIZE organizes and administers competitions looking to solve complex engineering challenges. One of the best-known XPRIZE competitions was the Ansari XPRIZE, which awarded the first team to fly three people to space and back twice within 14 days.

The NRG COSIA Carbon XRPRIZE will award $20 million in prizes to the teams that are best able to convert CO2 into other valuable products. Currently, 27 teams from six countries are working on ways to convert CO2 into things carbon nanotubes, methanol, building materials, fish food and plastics. The goal is to turn CO2 into an asset.

Later this year those 27 teams will be narrowed down to the final ten based upon the technical and economic feasibility. Five will test for two years at the ITC on coal derived flue gas and five will test in Canada at a natural gas facility. In 2020, the grand prize winners will be announced. When you add together all the funds the teams have already raised, the prize money and the costs of the facilities, the total Carbon XPRIZE investment is about $70 million dollars.

While on the surface, the prize money itself is not a significant amount in the overall energy R&D space, the competition model provides a few advantages. First, it provides a mechanism to vet technologies. Only the projects that work advance. Secondly, it sets an aggressive timeline. If they don't meet certain benchmarks, they don't advance. Thirdly, it opens to door to entrepreneurs and small inventors. Access to capital isn't an immediate barrier to entry. Lastly, the notoriety and public recognition for winning the competition will bring investors to them.

The model of providing a cash prize, following the testing, is a 180 degree turn from the current grant based model of funding R&D. However, it is hard to argue with the XPRIZE's success with the Ansari XPRIZE competition. One $10 million prize spurred 27 teams to invest over $100 million in technology development. Eventually, Richard Branson licensed the technology to create Virgin Galactic and today, the private space travel industry is worth $2 billion, only 22 years after the idea for a competition was created in 1995.

Last month, Apple celebrated the ten-year anniversary of the first iPhone model. This first version came with 4 GB of memory, a 2-megapixel camera, no flash, no zoom and no video camera. Today's iPhone 7 Plus has up to 256 GB of storage, fingerprint recognition, a 12-megapixel camera and HD video recording capabilities. Yes, today's CCUS technology is expensive and still evolving, but as we know, technology gets better and less expensive over time.

We need to begin to think about energy technology as we do with the technologies we utilize and take for granted every day and recognize the important contributions early government support provided to make them reality. Touch screen glass, which is a staple of today's smart phones, was developed in the United Kingdom funded Royal Radar Establishment in the 1960's for air traffic control use. GPS, canned food, microwave ovens, the internet, microchips, vaccines and nylon are items all developed by federal research.

Technology is 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 within the United States. However, every credible energy analysis from the UN Intergovernmental Panel on Climate Change to DOE acknowledges large amounts of coal will be used globally for the foreseeable future. Technology is the best way to ensure these countries have access to power, yet can meet environmental goals.

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

RESPONSES OF JASON BEGGER TO ADDITIONAL QUESTIONS FROM SENATOR BARRASSO

Question 1. The Wyoming Integrated Test Center (ITC) is a great example of what can be achieved when government, researchers, and industry work together to innovate. Can you discuss other initiatives related to Carbon Capture, Utilization, and Storage (CCUS) that the State of Wyoming is pursuing to support the transformation of carbon into a commercial asset?

Response. The State of Wyoming has been very proactive in developing all of the pieces necessary to commercialize carbon management technology by creating a number of entities focused on particular portions of the development chain. The University of Wyoming School of Energy Resources (SER) was created to host and develop the academic and bench-scale processes, with a goal of identifying which technology concepts are worthy of scale-up. The SER has state-of-the-art laboratory facilities, which includes a 3-D visualization center where researchers can literally walk into 3-D models of geologic reservoirs to study suitability for things such as enhanced oil recovery (EOR) and permanent geologic sequestration. The University has also created many Centers of Excellence, such as the Enhanced Oil Recovery Institute, which characterizes and identifies areas well-suited for CO2 EOR; and the Carbon Management Institute, which is currently characterizing two geologic formations for potential permanent CO2 storage.

The State has also created several independent entities to push carbon management. The Wyoming Business Council assists entrepreneurs looking to commercialize and establish a business, or businesses that are looking to relocate to Wyoming. The Wyoming Pipeline Authority works to develop pipeline infrastructure within the state, including CO2 pipelines that would be necessary. Last, the Wyoming Infrastructure Authority is tasked with developing large-scale, new generation technology projects. The Wyoming ITC is one such project.

The State of Wyoming's efforts have led to an entire network of entities from the SER looking at the basic research; to the ITC, where projects can scale-up; to the end users of CO_2 .

Question 2. What are the most important actions that the Federal Government should take to facilitate the development and scaling up of CCUS technologies for power plants across the nation?

Response. From a purely R&D perspective, you cannot force innovation through regulation or a politically mandated deadline. Innovation comes from incentives, adequate resources and reasonable timeframes. Many of the timelines with the Clean Power Plan were simply unworkable since even if the technology was commercial, it did not consider the time necessary to manufacture and install. A consistent R&D funding stream would provide the reliability necessary for researchers to undertake multiyear projects. One such avenue would be to divert the Federal Government's share of the Federal coal mineral royalty to technology development for a period of 10 years.

Utilities also need regulatory certainty. Certainly, economic forces such as low natural gas prices have hindered coal usage, however, natural gas prices have a relatively short commodity cycle of a few years, whereas a coal plant has a 50–60-year operating life. With such a long lifespan, utilities are hesitant to make multibillion-dollar investments without knowing the rules beyond the current Presidential administration. Through regulation, legislation, technology or a combination, utilities must have long-term certainty about how carbon will be managed.

It would also be helpful to recognize and incentive companies that are willing to host research projects or take undertake major pilot demonstration projects. While some may view the Kemper Project as a failure, Southern Company should be commended for attempting to push a major technological leap. R&D is risky and we need more utilities who are willing to scale-up technologies.

RESPONSES OF JASON BEGGER TO ADDITIONAL QUESTIONS FROM SENATOR WHITEHOUSE

CCUS Technologies General

Question 1. During the hearing, I mentioned several CCUS projects that have come online in recent years. This includes, the Iceland Carbfix Program, the Climeworks Direct Air Capture facility in Switzerland, the BioProcess H2O ethanol facility, and the Boundary Dam III carbon capture facility in the Canadian Province of Saskatchewan. These facilities cover a broad variety of CCUS technologies that includes coal, ethanol, permanent sequestration, and direct air capture.

a. Can you discuss the other promising CCUS technologies that have come online in recent years either at the pilot scale or larger? What are the economics of these projects that allow them to operate?

Response. A very important consideration of the economics of any project are the particulars of the country in which a project is commissioned. According to the Energy Information Administration, the average cost of electricity in the United States was 10.5 cents/kWh in 2016 (U.S. Energy Information Administration, 2017). That compares to 12 cents/kWh in Saskatchewan (city of Saskatoon, 2017), Switzerland is 20.6 cents/kWh (ALPIQ Group, 2017) and 16 cents/kWh in Iceland (Statista, 2017). All prices converted to US dollars. Another consideration is how or if electricity is subsidized. For example, electricity used for home heating in Iceland is subsidized by the government (Bar tir, 2004). A carbon price would also impact the economics. It is difficult to conduct a true "apples to apples" comparison across international boundaries without a full accounting of the various factors impacting what the end-users actually pay. Understanding these differences in prices helps understand something that may be economical in one country, may not be in another.

Two major projects in the United States are the Petra Nova and NET Power projects located in Texas. The Petra Nova is a commercial-scale, post combustion CCUS facility that utilizes solvent capture process to capture CO2 for use in enhanced oil recovery (EOR). The project is unique in many ways that assist with its economics. First, it received $190 million from the Dept. of Energy, a $250 million loan from the Japanese government and the owners, NRG and JX Nippon contributed $300 million. NRG is an independent power producer, meaning they simply sell power onto the open market, they do not serve specific customers. JX Nippon is a Japanese oil and gas company. Adding the uniquness is that Texas is an unregulated utility market, so NRG did not need to obtain permission from a Public Service Commission or other rate making body to undertake the project.

The NET Power project employs the Allam Cycle, which is a completely new process for utilizing fossil fuels to produce electricity while eliminating all air emissions, including carbon dioxide. A 50 MW pilot plant is scheduled to commence operations in November 2017 at a site in LaPorte, Texas.

Other researchers such as SES in Utah are working on cyrogenic carbon capture; TerraCOH from Canada, which is working on using pressured CO_2 stored geologically as a battery; and membrane separation technologies from MTR in California.

It is important to remember that first of a kind technologies are oftentimes not profitable without some sort of grant or financial assistance. Only after perfecting the technolgies in subsequent plants will the cost of manufacturing, construction and operations decrease to the point where it is truly economic. The key is to understand the price curve and path to commercialization with confidence at plant number x, it will become fully economicaly viable.

b. Can you also discuss what CCUS technologies you believe could be coming online over the next several years as it relates to both CCUS and direct air capture?

Response. The Allam Cycle is a very exciting new technology and could very well be the next generation power plant. However, as Wyoming has invested heavily in post-combustion research, we are very closely following those types of technologies, especially cyrogenic and mebrane separation.

Currently, we do not see a near-term promise for direct air capture. According to Massachusetts Institute of Technology researchers, the capture costs for the Climeworks project in Switzerland are nearly $1000/ton (Marshall, 2017). Other capture technolgies cost nearly 10 times less (Service, 2016). Simply put, we can capture ten times the CO2 for the same cost by using other methods.

c. What types of CCUS technologies hold the most promise as it relates to reducing our emissions to address climate change?

Response. In Wyoming, we are most interested in large-scale, commercial technologies that would produce large quantities of CO_2 that could be used for EOR or conversion technologies. We believe industrial settings, at or near large, stationary sources, provide the best economics.

While there are many oportunities to refine and improve amines, largely, CO_2 capture via amines is considered close to commercial today since it is being utilzied at full-scale at sites such as Petra Nova and Boundary Dam. For post-combustion retrofits, membranes that would filter away the CO_2 hold great promise.

With regards to new combustion technologies, oxy-fired and the Allam cycle are technologies that would utilize fuel in an entirely different way,

Carbon Utilization

Question 2. To address climate change we must reduce our emissions from multiple sectors including the power, industrial sector, and transportation sector. As discussed during the hearing, BioProcess H2O is a unique as it reduces emissions from an ethanol plant.

a. What are the different forms of carbon utilization that have proven to work at the pilot scale? In your opinion what are the promising carbon utilization technologies that have not yet been tested at the commercial scale?

Response. CO_2 is a chemical compound and if it is simply considered a feedstock consisting of carbon and oxygen, the wide array of products that can be produced is limitless. However, the CO_2 has very strong, double covalent bonds. This renders CO_2 an incredibly molecule necessitating large amounts of energy to break the carbon and oxygen apart. Plant photosynthesis is a natural molecule splitting process, which is why many CO_2 management projects utilize some sort of plant production component. Companies such as LanzaTech are using CO_2 to feed microorganisms which will be converted into biofuels.

Other projects seek to use the CO_2 as a feedstock in their process. A British company, Carbon 8, is using CO_2 as a catalyst to create artificial limestone, which is turned to aggregate and cinder blocks for construction. Covestro is a company producing plastics and materials from CO_2 .

Wyoming's largest relationship in carbon utilization is with the NRG COSIA Carbon XPRIZE, which will conduct the final round of their competition at the Wyoming ITC. Currently, 23 teams from six countries are working on processes to capture CO_2 from an operating coal-fueled powerplant and convert them into some marketable product. These teams are currently focused on products such as fish food, fertilizer, carbon nanotubes and building materials. Full team profiles and summaries of their technologies can be accessed at: https://carbon.xprize.org/teams.

b. What does carbon utilization mean for the overall economics of making CCUS projects more cost competitive?

Without government assistance, carbon utilization is necessary to improve the economics until the capital and operating costs are hopefully reduced in subsequent plants. The first of a kind plants are the most expensive and the lessons learned building and operating them lead to future cost decreases. NRG acknowledges that they could build a second Petra Nova unit at a cost 15 percent less than the original.

Also, the utilization of the CO_2 provides an additional revenue stream. EOR is the simplest and most widely utilized use of CO_2 today. Selling theCO_2 to an EOR operator could provide $25–30/ton to help offset the cost of the capture. Converting the CO_2 into an even higher value product, such as carbon fiber, could lead to revenues that exceed the cost of capture and make CCUS economically profitable.

In Wyoming, we believe market based solutions toward CCUS will ultimately be more successful than government mandates. If CCUS is a revenue generator rather than an expense through regulation, technology will develop even faster. A win-win is removing CO_2 and creating a new industry.

c. Can carbon utilization play a major role in reducing the cost of capture for CCUS projects?

Absolutely. If the products or end use of the CO_2 sells for more than the cost of the capture, the business opportunity will push technology. Free markets drive innovation and cost declines much more quickly than government mandates.

EMISSIONS FREE GRID BY 2050

Question 3. Each witness from the hearing discussed different clean air technologies that if developed and commercialized can reduce our emissions footprint. There is international agreement that CCUS and other renewable technologies can play a role in helping us cut emissions consistent with meeting our 2C targets, in a way that is sustainable and economically sound.

a. Why are your labs prioritizing research in clean energy technologies like this?

Response. The State of Wyoming currently receives approximately 70 percent of it's entire tax revenues from mineral extraction. Acknowledging societal concerns regarding carbon emissions, the State recognized nearly 15 years ago that advances in technology was a proven way to mitigate environmental concerns. Since the early 2000's, Wyoming has invested millions in funding new research and facilities with the goal of sustaining its tax base, while advancing clean energy tech.

b. What role will advanced nuclear and carbon capture and utilization play in helping us meet our climate targets and having an emissions free grid by 2050?

Technology is 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 within the United States. However, wind farms and renewable alternatives still face long permitting timelines and intermittency challenges. For example, the Sierra Madre/Chokecherry Wind Farm and the associated TransWest Express transmission line planned for Wyoming would be the largest on-shore wind farm in the United States, delivering 3000 MW of electricity to the Southwest U.S. This project filed its first permits in 2007 to the Bureau of Land Management, U.S. Fish Wildlife Service and associated Federal agencies during the last year of the Bush administration. They did not receive their final permits until 2017 under the Trump Administration. The permitting timeline was 10 years and cost over $125 million. The lengthy, expensive and complicated permitting requirements for new wind farms an incredible barrier to entry for large amounts of renewables in the Western U.S. to be added to the grid.

Every credible energy analysis from the U.N. Intergovernmental Panel on Climate Change to DOE acknowledges large amounts of coal will be used globally for the foreseeable future. The world will not see an emissions free grid without CCUS.

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 CO_2 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, CO_2 for enhanced oil recovery, CO_2 for conversion and use as various products, and even carbon removal technologies which pull CO_2 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 CO_2 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 CO_2 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 CO_2 underground.

In looking to the future, Livermore is engaged in the development of revolutionary new technologies with industrial partners to manage CO_2 emissions by turning CO_2 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 CO_2 is the driving force for new products and new enterprises in which innovation and entrepreneurships creates new companies and wealth by capturing and converting CO_2 into value-added products.

Employing out-of-the-box thinking, the Lab is embarking on a bold new approach to manage CO_2 at large scale, and simultaneously providing carbonate sands for cement manufacture and beach replenishment and elevation gain by extracting CO_2 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:]

Senate Environment & Public Works Committee
Subcommittee on Clean Air and Nuclear Safety
Developing and Deploying Advanced Clean Energy Technologies
July 25, 2017

Dr. Steven R. Bohlen, Lawrence Livermore National Laboratory
Written Testimony

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 portfolio at Lawrence Livermore National Laboratory (LLNL).

My testimony seeks to provide an update on the status of carbon capture, use, and storage (CCUS), with emphasis and focus on CO_2 utilization (CO_2U) and carbon removal (CR). This includes assessment of current technologies and their readiness, activities in technology development at my Laboratory (LLNL), and several projects and initiatives ongoing around the world in which LLNL has been involved that foreshadow a future in which CO_2 becomes a feedstock for valuable products.

Management of carbon dioxide emissions is not just viable – the technology exists today, is deployed and operating, and functions as designed. Technology for converting CO_2 into materials we use every day is developing rapidly. These provide new possibilities for commercial enterprise in the US, as well as to provide opportunities for commercial and technical leadership. It is possible to improve the environment while generating revenues. Innovation lies at the heart of this new carbon economy, and both basic and applied R&D are needed to make best advantage of the opportunities in this competitive and dynamic landscape.

Clean energy demand continues to grow worldwide, with investment of nearly $400B in 2015 and 2016, and carbon capture, use, and storage (CCUS) remains a growing, but underutilized element in the clean energy industry. CCUS includes carbon capture and storage (CCS), CO_2 enhanced oil recovery (EOR), CO_2 conversion and use (CO_2U), and even carbon removal technology (so called negative emissions approaches which pull CO_2 from the air and oceans). These different pathways provide 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 with six more planned, 22 will be operating by 2020 (Figure 1). These include power and industrial projects, new build and retrofits, and both CO_2-EOR and saline storage, with over a third in North America. Costs have come down, performance has improved, and new technologies have been born that show that CCUS can be cost competitive today with many clean energy technologies in many markets (Lazard, 2016, see below). In some sectors, like heavy industry (refining, cement manufacture), CCUS is the only option available at scale today for carbon management.

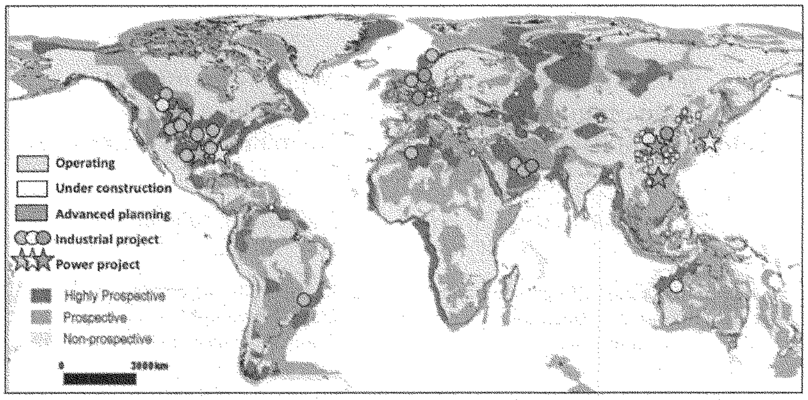


Figure 1: Operating and soon to be operating CCUS projects worldwide. Over one third of these are in North America.

The mission of the Department of Energy's National Laboratories is to advance science and technology that address issues of today and to foresee important pending national and global challenges and help provide solutions to them as well. Much effort is focused on developing new technologies, often in close partnership with companies who can bring these technologies to market. The challenges of a sustainable national and global environment, threat reduction from extreme climate events, and providing an engine for US competitiveness have led to federal investment in research and analysis conducted at LLNL and other Labs on projects and problems to manage carbon through CCS, CO_2U, and Carbon Removal.

Grounded in our expertise in novel materials, modeling and simulation, and carbon life-cycle expertise, for nearly two decades LLNL has been funded to work on CCUS and has been a partner in most of the carbon capture and sequestration projects nationally and globally. As a result, LLNL has developed analysis tools and early-stage technologies for CO_2 removal from the air and oceans. Recently, this has expanded to include conversion of CO_2 to useful products such as methane, methanol, and ethylene, much of which is enabled by advanced manufacturing technologies and advanced computer simulation of catalyst efficacy.

In dealing with the problems of today, LLNL and other laboratories provide technical expertise, modeling and simulation, and actionable solutions for the challenges of EOR and CCUS.

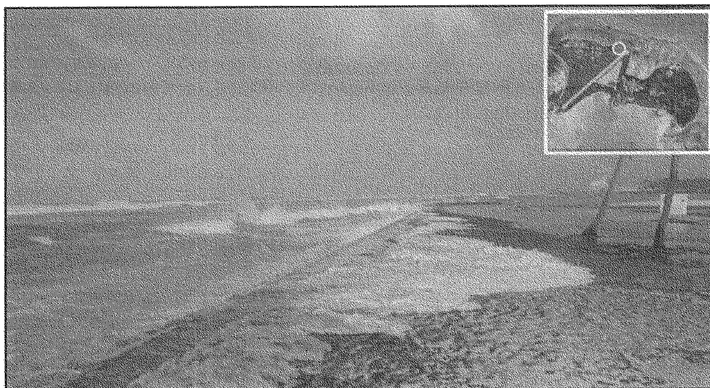
- Today, LLNL provides the most advanced 3-D fracture mechanics modeling for industrial partners for managing the risk of induced seismicity for hydraulic fracturing operations, EOR, and underground carbon sequestration projects.
- LLNL scientists have provided technical and modeling expertise for most large-scale geologic carbon sequestration projects globally, and the safe long-term storage of several tens of millions of tons of CO_2 underground.
- LLNL has developed technology that can feed CO_2 to algae with low cost, high efficiency, and minimal CO_2 losses. This could improve biofuels production cost, performance, and geographic range.

- In partnership with Iowa State University and Easy Energy, LLNL has launched an effort, funded by the California Energy Commission, to convert forestry wastes to biofuels through fast pyrolysis. This technology also produces biochar, a charcoal-like substance that improves soil performance while storing air-removed carbon. A pilot field project is anticipated by 2019.

In looking to the future, LLNL is engaged in the development of revolutionary new technologies with industrial partners that seek to manage CO_2 emissions by turning CO_2 into a valuable feedstock for new industries and technical capabilities that are economically viable and convert CO_2 into useful products – fuels (methane and biofuels) and chemical feedstocks (methanol, ethanol, and ethylene). Indeed, we see a society that is poised at the edge of a new carbon economy – one that harnesses innovation and entrepreneurship to create new products, companies, and wealth through capturing and converting CO_2 into value-added products. Many see this industry as potentially enormous, possibly of a size and scale comparable to agriculture, oil and gas, or power sectors today.

- Combining simulation, advanced manufacturing, and new materials, LLNL has discovered both direct and biologically mediated pathways to convert CO_2 to chemical feedstocks and fuels. The current work focuses on converting CO_2-to-ethylene, a critical feedstock for plastics and petrochemicals.
- LLNL is embarking on a bold, new approach to managing at a large scale and simultaneously providing sand for cement manufacture or beach replenishment and elevation gain.

Though in its embryonic stages, the process takes advantage of the ocean's high calcium carbonate content. By removing CO_2 from ocean water, excess calcium carbonate precipitates as fine grains of sand. This happens naturally, particularly in the Caribbean and the Red seas, but can also be induced by using LLNL's encapsulated solvent technology to remove CO_2 from ocean water. The sand that precipitates can be used to build beaches in remote areas such as the US missile test site on Kwajalein Atoll. Currently the only source of building material in the southern Pacific islands comes from the destruction (dynamite) of the reefs to provide material, for example, protection from rising sea level. With advancements in this new technical approach, it could become possible to generate large amounts of carbonate sands for increasing low-lying island elevations and protecting infrastructure. With the removal of CO_2 via LLNL's encapsulated solvents, CO_2 produced must be stored underground in the volcanic core of the atoll, or, more beneficially, converted into a useful product such as gasoline using technology like that developed by 3M and Oxide Materials. Renewable energy would power such systems.



During the March 2, 2014 overwash event in the Republic of the Marshall Islands, seawater regularly topped the manmade perimeter berm on the island of Roi-Namur and covered large areas of the adjacent land surface. Shown are runways and radar dishes on the US Army Base Kwajalein Atoll Missile Range https://walrus.wr.usgs.gov/climate-change/atolls/news.html#oct15 The LLNL technology could *potentially* create carbonate sand to provide a berm perimeter and raise the elevation in important areas.

Like the National Labs, groups within US universities are also making advances in CCS, CO_2-EOR, and CO_2U. As examples, the US DOE Hub at the California Institute of Technology has led a program for over seven years in converting CO_2 to fuels photochemically (using sunlight to make fuels). Stanford, MIT, and Northwestern University have similar programs. Iowa State University and University of Illinois have programs on bioenergy with CCUS. And recently, Arizona State, Iowa State, and Purdue University launched a new consortium[1] with LLNL and the Center for Carbon Removal focused on creating the knowledge and practice needed to draw economic value from carbon removal and CO_2 conversion and use.

US institutions are not alone in this effort. Universities, research institutes, and National Labs in other countries have taken up this challenge as well. Groups in Canada, Mexico, Europe, the Middle East, and East Asia are busy and growing, and governments in those regions are increasing their investments in CCS, CO_2-EOR, CO_2U, and carbon removal. Despite US progress and investment to date, it is not clear that the US leads the world in this area.

Global Operational Project Review

As noted, numerous projects are operating in the world today, with several more coming online by 2020, in total over 20 projects that sequester CO_2 at industrial scales. Together, these will inject 40 million tons of CO_2 underground – like pulling eight million cars off the road. The overwhelming majority of these projects has been completed on time and on budget, and has a successful high-capacity operating history.

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[1] https://www.newswise.com/articles/new-carbon-economy-effort-launched-at-arizona-state-university

Among these projects, there are several noteworthy projects for the Committee's consideration.

PetraNova[2]: NRG, in partnership with JX Nippon and Hilcorp Energy Company, retrofit the W.A. Parish power plant near Houston, TX. Roughly 1.6 Million tons are captured by the liquid solvent technology, provided by Mitsubishi Heavy Industries, and stored during enhanced oil recovery. The project came in on time and on budget. The operators and partners say that a second project at the same site could be done for roughly 20% lower costs.

Port Arthur[3] **and Quest**[4]: These two industrial projects capture and store CO_2 which is a byproduct of converting methane to hydrogen. This produces very low-cost, zero-carbon hydrogen – the cheapest in the world so far. The Air Products project at Port Arthur stores the CO_2 through EOR. Shell's methane reform project at Quest stores CO_2 in a saline formation.

China: Many CCUS projects are moving forward quickly in China. Dr. James Wood's testimony will explain this in some detail. However, it is worth noting that three large commercial projects are coming on line in the next four years, and that the Chinese Academy of Sciences has tasked a new research institute in Shanghai[5] for the sole purpose of CO_2 conversion to useful products.

NetPower Pilot Plant: NetPower[6] is a North Carolina-based company that uses "Allam cycle" combustion – oxygen-fired natural gas turbines that use supercritical CO_2 as both the working fluid and mass to the turbine. The NetPower system has the same cost as a natural gas power block, has a physical footprint, and requires no water for cooling (in some configurations, the plant produces water). A pilot demonstration[7] near Houston has finished construction and begun component testing - it should be operational in fall 2017, with Exelon, Chicago Bridge and Iron, and Toshiba as commercial partners.

Climeworks Direct Air Capture Plant[8]: A small Swiss company, Climeworks, has created the first commercial, for-profit project that captures CO_2 directly from the air. They capture and sell 900 tons per year of CO_2 to an organic greenhouse. This technology is mass-producible, scalable, and robust.

Carbon removal power plant: Climeworks is partnering with Reykjavik Energy in Iceland and Lawrence Livermore National Laboratory to make the world's first power plant with less-than-zero carbon emissions. Based at the Hellisheidi Geothermal Power Station[9], Climeworks is installing their direct-air capture system. CO_2 drawn from the air will then be injected into the deep basaltic rocks below the plant, part of the CarbFix project[10]. LLNL will work on the monitoring and validation of the CO_2 injection as well as the life-cycle analysis of the carbon footprint.

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[2] http://www.globalccsinstitute.com/projects/petra-nova-carbon-capture-project
[3] http://www.globalccsinstitute.com/projects/air-products-steam-methane-reformer-eor-project
[4] http://www.globalccsinstitute.com/projects/quest
[5] http://english.sari.cas.cn/
[6] http://www.netpower.com
[7] https://www.forbes.com/sites/christopherhelman/2017/02/21/revolutionary-power-plant-captures-all-its-carbon-emissions-at-no-extra-cost/#5db22e3d402d
[8] http://www.climeworks.com/
[9] http://www.onpower.is/about-us
[10] https://www.or.is/english/carbfix-project

Carbon Recycling International's Renewable Methanol Plant[11]: Also in Iceland, Carbon Recycling International has built and operated a plant that converts CO_2 to methanol, a chemical feedstock and transportation fuel. Using clean electricity from the Svartsengi geothermal power station, they make hydrogen from water and combine the renewable hydrogen with CO_2 to make methanol. This fuel is sold to ferries in Europe which use the methanol to power fuel cells.

NOTE: The increased availability of low-cost, distributed clean power and heat helps to create new industries like Carbon Recycling International that convert CO_2 to products. Part of the likely market value of these products is the low carbon footprint. If so, then the demand for clean energy will grow as these companies gain market share – part of a new carbon economy.

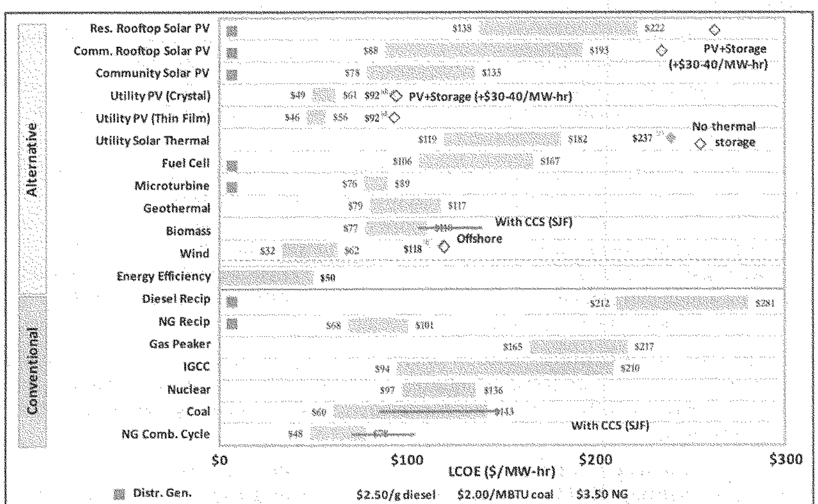

Figure 2: After Lazard (2016). Red bars reflect reported costs from commercial projects and price estimates based on DOE and NETL reports on existing technology in the market today.

Power Applications: Range of Costs and comparisons to other technologies

CCUS has many applications, including power, heavy industry (see below), and 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 also be applied to biomass, natural gas, biogas, and even fuel cell power systems. Contrary to common opinion, the CCUS power costs are rapidly becoming competitive today on an unsubsidized cost basis with many other technology options (Figure 2). On an unsubsidized basis for the levelized cost of electricity (LCOE)[12], power from gas, coal, or biomass (with CCS, noted as a red line in the figure above) is cheaper than that of

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[11] http://carbonrecycling.is/

[12] Lazard, 2016. Levelized cost of electricity analysis 10.0. https://www.lazard.com/perspective/levelized-cost-of-energy-analysis-100/

offshore wind, new nuclear power, rooftop solar PV, concentrating solar, and community solar PV with batteries in many US markets.

Today, post-combustion retrofits on a supercritical coal plant using amine-based solvents are possible and in some case the lowest cost pathway to decarbonization. For example, the PetraNova plant described above reduced 90% of the emissions from one unit without derating or decline in power output. In addition, opportunities for cost reduction are significant even with the same CCUS-systems. Coal-plant operators in the US and Canada have stated that they could reduce costs by 20% redoing the same plant, and that the fourth plant would achieve 40-50% cost savings relative to the first.

Industrial CCUS in the US

Many heavy industries, representing 20% of global emissions, lack other options to decarbonize. Cement, steel, refining (and biorefining), chemicals, and glass making are particularly difficult cases. For cement and steel making, much of the emissions are a direct consequence of fabrication chemistry. For such systems, CCUS is currently the only available option.

In many cases though, by-product CO_2 is highly-concentrated (e.g., for ethanol, biodiesel, fertilizer production, natural gas sweetening, refining, and petrochemicals). These can be captured and stored at relatively modest cost. In the US, the all-in-cost of CCS, including polishing, compression, transport, and storage, is less than \$30 per ton CO_2 – in some cases less than \$20. ***Over 43M tons per year could be stored at this low cost.*** [13]

For this reason, perhaps unsurprisingly, most CCUS projects around the world are industrial projects. These include Emirates Steel (the first ultra-low C metallurgical plant), the Uthmaniyah refinery in Saudi Arabia, the Quest upgrader project in Alberta, the ADM ethanol plant in Decatur, Illinois, and the Air Products plant in Port Arthur, TX.

[13] www.betterenergy.org/American_CO2_Pipeline_Infrastructure

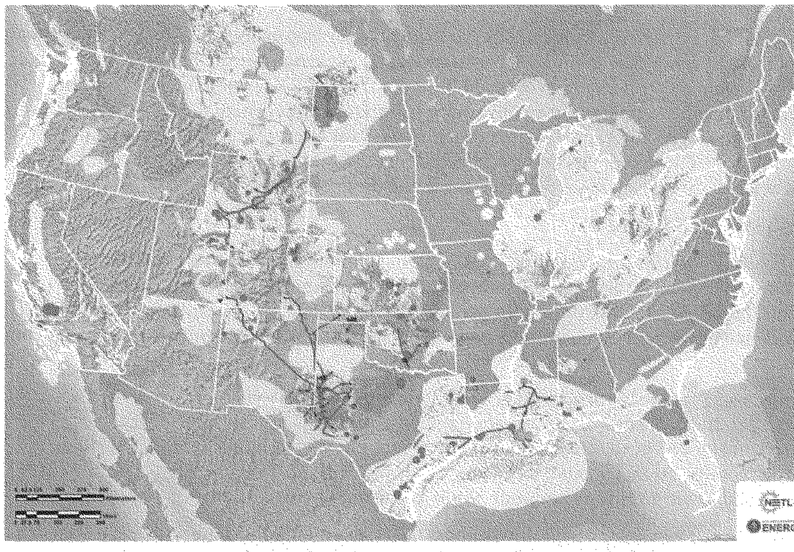

Figure 3: High-purity CO_2 sources within 100 miles of potential CO_2 storage sites. Green areas represent oil fields; light beige areas represent saline formations for storage.
Yellow dots = ethanol plants; purple dots = fertilizer plants; red = petrochemicals plants; orange = oil and gas refineries.

Summary

As stated at the outset and recapitulated here, management of carbon dioxide emissions is not just viable, it is a technology that exists today, is deployed and operating, and works as designed. Technology for converting CO_2 into materials we use every day is developing rapidly. These provide new possibilities for large-scale commercial enterprise in the US, as well as to provide avenues for commercial and technical leadership. Improving the quality of the environment and generating revenues is not a dream, it is a reality today. Innovation lies at the heart of this new carbon economy, and both basic and applied R&D are needed to make best advantage of the opportunities in this competitive and dynamic landscape.

RESPONSES OF JASON BEGGER TO ADDITIONAL QUESTIONS FROM SENATOR WHITEHOUSE

1. CCUS TECHNOLOGIES GENERAL:

During the hearing, I mentioned several CCUS projects that have come online in recent years. This includes, the Iceland Carbfix Program, the Climeworks Direct Air Capture facility in Switzerland, the BioProcess H2O ethanol facility, and the Boundary Dam III carbon capture facility in the Canadian Province of Saskatchewan. These facilities cover a broad variety of CCUS technologies that includes coal, ethanol, permanent sequestration, and direct air capture.

Question 1. Can you discuss the other promising CCUS technologies that have come online in recent years either at the pilot scale or larger? What are the economics of these projects that allow them to operate?

Response. There are many projects and approaches that highlight the state-of-the-art today and what is possible soon. Direct air capture projects (e.g., the Climeworks project in Zurich) are discussed in section 3 below.

- PetraNova, Texas: Using Japanese technology (Mitsubishi Heavy Industries), NRG retrofit a Houston supercritical coal unit for 90 percent CO_2 capture. Roughly 1.4 million tons CO_2/y are used for enhanced oil recovery. Unit costs are roughly \$100/ton CO_2 , which is comparable to reduction costs achieved by many other clean power technologies, with substantial room to reduce costs in the 2nd–4th plants. Economics are possible due to revenues from enhanced oil recovery sales, a novel business structure where NRG owns part of the oil field receiving CO_2, and a \$227 million grant from the US Dept. of Energy.
- Al Reyadah, Abu Dhabi: This project takes 800,000 tons/y of by-product CO_2 from a steel mill and uses it for enhanced oil recovery. Conventional pre-combusion separation technology (Selexol) separates CO_2 from syngas. Unit costs are estimated to be between \$15–25/ton CO_2 . The economics are possible due to revenues from enhanced oil recovery sales, low power costs for compression, and the low cost of compressing and transporting pre-concentrated by-product CO_2 from the steel plant.
- NetPower, Houston: This new, advanced power cycle uses supercritical CO_2 as working fluid in the turbine, and combusts natural gas or coal syngas in an oxygen and CO_2 rich synthetic air. The pilot plant is fully constructed and is under testing now (more details in section 1.b on economics and opportunities for deployment). Economics are possible based on lack for CO_2 storage integration and private investment of private capital from industrial partners.
- Archer Daniels Midland (ADM), Illinois: High-concentration, by-product CO_2 from an ethanol fermenter in Decatur is compressed and injected into a deep saline formation. Economics are made possible by a \$180M grant from the US Dept. of Energy, which covers capital and operating costs, as well as low-cost power for compression.

NOTE: This project would be commercial today if ethanol from this plant sold into California under the Low-Carbon Fuel Standard (\$80–120/ton CO_2). It is anticipated that ADM will take advantage of this revenue source once the State of California completes its accounting standard for CCS, scheduled for 2 years from now. Many ethanol producers are looking forward to this CCS economic boost, which we estimate will provide about \$0.20/gallon in additional profit for ethanol with CCS (including the cost of the CCS system).

The Department of Energy estimated in the recent Billion Ton Report that the U.S. could reliably produce 1.5 billion tons of biomass for biofuel production. Typically half of the carbon in biomass is emitted as CO_2 during processing. If all of this biomass were treated in facilities with CCS like ADM, as much as 750 million tons of CO_2 could be sequestered. This CO_2 has been captured from the atmosphere by the agricultural plant growth, and the sequestered amount would be 'negative' emissions. The capture technology is well-demonstrated to achieve this goal, but storage options need to be developed.

Most of these projects are in the US with American companies. The economics of every project required some additional revenues, grants, or funds to close a financial gap for these first of a kind sequestration operations.

Question 2. Can you also discuss what CCUS technologies you believe could be coming online over the next several years as it relates to both CCUS and direct air capture?

Response. Yes.

- NetPower: NetPower is using the Allam cycle—a new, high-pressure/high-temperature gas oxycombustion approach that remains above the supercritical point for CO_2 through the whole cycle. If it works as predicted, it will combine high efficiency of gas turbines with 100 percent CO_2 capture at near-zero additional costs. The unit is being tested at the Houston pilot plant now. NetPower would be the first in line to provide a zero-Carbon natural gas project in the U.S. (and in the world).

This technology could be a game-changer in the U.S. with our large natural gas reserves and geologic storage capacity. It requires all new-plant construction (cannot be retrofit to existing plants) but offers an intriguing option for renewable integration; for the last 3 years new power plant construction in the U.S. has been a mix of gas, wind, and solar, roughly 1/3 each. Constructing new gas plants that meet the NetPower expectations would make that mix a zero-carbon solution.

- Reykjavik Energy, CarbFix, and Climeworks: Today, Climeworks captures CO_2 from the air and sells it to a greenhouse. They are working with an Icelandic geothermal power company, Reykjavik Energy, to create the world's first negative emissions power plant. The preferred site is at the CarbFix project, which reinjects CO_2 into the basalt formations of geothermal production zones, where it mineralizes as new carbonate minerals. They plan to integrate the Climeworks technology at the CarbFix site, and hope to sell the service of negative emissions to potential buyers.
- Carbon Recycling International in CA: A number of technologies and companies convert CO_2 into chemicals and products, including methanol (which can be used as a transportation fuel, cooking fuel, or feedstock chemical). Carbon Recycling International is an Icelandic company that combines renewable hydrogen with CO_2 and heat to make methanol, which they sell to the European market. They have a subsidiary office in Los Angeles, which is exploring the possibility of integrating direct-air capture technology with CO_2 -to-methanol conversion in California. These fuels would benefit from the low-carbon fuel standards and air-quality control regulations in CA, and may be commercial there.
- Biomass Conversion with CCS: Converting the wood and fiber left over from agriculture and forestry is being pursued by a number of small ventures including a partnership of Easy Energy and Iowa State University who are working with LLNL and the State of California to demonstrate conversion of forest waste into bio-oil by pyrolysis, a fast heating process. About 20 percent of the waste is turned to charcoal, or biochar, that can be used to improve farm soils while permanently storing carbon, making this a negative emissions process. The pyrolysis approach only requires small equipment that can be moved near the biomass source, rather than facing the transportation problems of large biomass energy plants.
- Other Industrial CCUS—Like the ethanol and fertilizer plants of the US breadbasket, many industrial belts in the US have large-volumes of near-pure CO_2 that could be stored, used for EOR, or serve as feedstocks for CO_2 conversion. One important example is along the Gulf Coast, including Mississippi, Louisiana, and Texas. In particular, CO_2 from these sources could be applied in offshore carbon storage and EOR sites. These would take advantage of existing infrastructure, namely near-shore platforms that are close to decommissioning. Storing CO_2 would help delay decommissioning costs, saving money and creating more resource.

Question 3. What types of CCUS technologies hold the most promise as it relates to reducing our emissions to address climate change?

Response. The efficient conversion of biomass to products like fuels is the low-hanging fruit of CCUS today. Ethanol plants emit pure CO_2 for storage or reuse, thermal processes make biochar for soil improvement, and good crop management improves soil carbon. The products benefit from Federal RINS and State LCFS economics. These efforts need to demonstrate that they are effective, and quantify their final carbon footprint. 'Air capture' through biomass is already a pillar of the U.S. economy in our agricultural and forestry management systems. All of the direct air capture systems have these economic benefits and demonstration challenges—it is convenient to consider them in the same light.

Liquid fuel production, and CCS associated with it, address the largest source of U.S. CO_2 emissions: transportation. Great progress has been made in electric power generation, but transportation gains have been limited to efficiency. Biofuels are an important part of this, as is creation of hydrogen from natural gas with CCS. This is a low-cost option today, and hydrogen can be used as a fuel itself, or to upgrade other fuels, even to make fuels directly from CO_2 . Hydrogen is an important industrial product, and three projects (including the Shell Quest project in Alberta and the Air Products project in Texas) demonstrate that zero-carbon hydrogen production from natural gas plus CCS is a commercially viable approach that is technically mature.

We have been very focused on CCS in coal fired power, and those technologies are maturing. Options like NetPower (see above, sections 1.2 and 1.1) could completely reshape our carbon emissions. With the impressive gains in renewables, a carbon-free U.S. grid is in sight. Electrification and reduction of the carbon footprint of liquid fuels can make major progress in transportation. But key industrial emissions like steel, concrete, glass, and chemical production need new options.

A thorny problem is that captured CO_2 needs to be transported to its storage or use point. Creation of pipeline systems to provide this service would greatly reduce the cost. Some future options for utilization of CO_2 , such as creating ethylene from CO_2 via electrocatalysis, could facilitate local usage of CO_2 at the source. Inexpensive hydrogen from natural gas with CCS would enable the decarbonization of many industrial processes including steel production.

Norway has just undertaken an effort to completely decarbonize its industrial sector via CCS. The industrial sources include cement, fertilizer, and waste-to-energy (trash burning).They will use ship transport of CO_2 to a single storage site in the North Sea. The industries are responsible for capture at their site, but the government is taking responsibility for the transport and storage, including liability issues. The ship transport demonstration is unique in the world, and could be applicable in the U.S. Gulf Coast where most emitters are along shipping lines, and there is huge capacity offshore.

Finally, there are many other promising CCUS technologies nearing technical readiness. Chemical looping is one example—it draws the energy from fuels very efficiently without burning them through direct chemical reactions. New solid sorbents present potential breakthroughs in both capital and operating costs, and may prove sufficiently robust for direct air capture. Advances in advanced manufacturing, like the microbead capture technology developed at LLNL, hold promise for dramatic cost reduction and the ability to deploy CCS at distributed sources. Many of these technologies require more time and funding before they could enter the market competitively.

2. CARBON UTILIZATION:

To address climate change we must reduce our emissions from multiple sectors including the power, industrial sector, and transportation sector. As discussed during the hearing, BioProcess H2O is a unique technology as it reduces emissions from an ethanol plant.

Question 4. What are the different forms of carbon utilization that have proven to work at the pilot scale? In your opinion what are the promising carbon utilization technologies that have not yet been tested at the commercial scale?

Response.

- Enhanced oil recovery is the major success in carbon utilization. Programs that incentivize storage could increase use of CO_2 in EOR to the point that the oil produced is carbon negative (more CO_2 stored than emitted in burning the fuel). This may prove particularly important in developing CO_2 -based EOR in residual oil zones (ROZ), which account for over 200 billion barrels of estimated resource in Texas alone.
- Feeding CO_2 to algae is a surprising success. Algae uses CO_2 to make biomass and are limited in their growth if they only get it from the air. Programs to add CO_2 to the ponds show significant increases in productivity, while also demonstrating reduction in the cost to capture the CO_2 because there is a much simpler separation system (for instance, high compression is not needed). Algae is converted into valuable chemicals, animal feed, and in the future, fuels.
- An early target of CO_2 utilization efforts was in cement and concrete production. Those efforts have created businesses like CarbonCure, who add CO_2 to concrete, resulting in a new reduction in the carbon footprint because the concrete is stronger, and less is needed, in addition to the CO_2 incorporated. A number of companies are pursuing similar goals. Transportation of the CO_2 to the concrete plants is a barrier, as is the technical understanding of all the mechanisms which incorporate CO_2 into cement.
- LLNL is working with Stanford University to produce methane from CO_2 with renewable energy. Both physical catalysts and biologic pathways are being evaluated. The low cost of renewable energy makes this potentially viable even in the U.S. if there are carbon emissions goals, such as those in California. Both major gas utilities in California are interested in this as a way to utilize their existing natural gas infrastructure in a zero-carbon economy.
- Laboratory studies have shown that CO_2 can be converted in to chemicals and fuels. The ARPA-E supported process from Oxide Materials and 3M produces gasoline from CO_2 and water using renewable electricity. A number of studies, notably those of Jarmillo at Stanford University, show that many if not all industrial chemicals can be made in this way. Ethylene, with 200 million tons of annual worldwide production resulting in 300 million tons of CO_2 emissions is a target for electrocatalytic production. Total, the French oil company, is working with LLNL to

achieve this goal in hopes of decarbonizing their chemical products sector. Shell Oil has created an entire division to look at producing chemicals by this means, and also how to provide the large amounts of CO_2 that will be required.

With renewable energy prices dropping steadily, we are optimistic that these approaches can become competitive with existing fossil-fuel approaches. In the event that long-lived products like polyethylene are produced, these processes become carbon negative. Future production of carbon fiber and carbon nanotubes is being investigated. These utilization approaches would both reduce our fossil fuel emissions, and create real negative emissions needed to hit our 2 degree C targets.

Question 5. What does carbon utilization mean for the overall economics of making CCUS projects more cost competitive?

Response.

- Utilization for EOR is generally considered to provide $30/ton of CO_2 in economic support. CO_2 use in concrete by CarbonCure reduces the overall cost of the product by making it slightly stronger. Use of CO_2 for algae may reduce the cost of carbon capture by 50 percent (these are very preliminary studies, but the reduction in expensive equipment is the main benefit).
- Future payments through the California LCFS (Oregon and British Columbia are starting similar systems) could reduce the cost of ethanol with CCS by $0.20/gallon including the costs of the CCS system. This is the only case that we know of where an actual profit, rather than a reduction in costs, accrues to CCS, and we expect it to revolutionize the Midwest U.S. ethanol industry. Unlike the EOR reduction however, this is a result of a policy action.
- The cost benefit of chemical and fuel production from CO_2 is not yet clear, but is not expected to be better than current embedded systems using fossil fuels until three events occur:

1. Renewable energy is widely available.
2. Effective systems to utilize these catalytic approaches are demonstrated, and,
3. CO_2 supply is easy and inexpensive (a carbon economy exists).

- We expect CO_2 utilization to grow just as wind power did in the United States: early success at demonstration scale, a long period of industrial and business development, followed by unsubsidized commercial success in the not too distant future.

c. Can carbon utilization play a major role in reducing the cost of capture for CCUS projects?

- CO_2 utilization doesn't actually reduce capital or operating costs—what it does is create new revenues. The additional revenues can be large enough to substantially reduce the integrated project costs and close the gap in financing projects.
- It already plays a major role in the large number of projects where EOR is utilized, and policy support for those efforts is likely to cause an increase in CCS projects. Algae efforts could play a major role to the extent that algae producers are successful in creating markets for their products (fuels are not considered a near-term economic target). They are gradually doing so. Turning CO_2 into new products, such as fuels and chemicals, is still in the research stage and is not likely to provide short-term cost reductions in CCS, although in the long run these may provide the carbon economy required to completely decarbonize our industrial and fuel sectors that currently lack options to meet 2050 targets.

3. DIRECT AIR CAPTURE:

The Climeworks direct air capture project in Zrich is a capture facility connected to an existing garbage incinerator that generates waste heat. This waste heat is used to power fans in the direct air facility, which suck outside air into a compressed air chamber. The plan is for the facility to take in 900 tons/year of CO_2 , but the cost of capture for these types of plants is roughly $600/dollars a ton.

Question 6. Dr. Bohlen why is the cost of capture for direct air capture so high? What can bring down the costs to make this technology more feasible?

Response. The costs for CO_2 capture from air will always be more expensive than capture from power plant or industrial sites. This is because CO_2 concentrations are much lower in air (0.04 percent CO_2) than from flue gas streams (4–7 percent from natural gas power, 12–20 percent from coal power, nearly 100 percent from ethanol fermenters, and 1–35 percent from most heavy industry smokestacks). The low partial pressure of CO_2 from air requires large surface area contactors, or much large systems, or much more strongly binding capture agents. All of these add substantial capital and/or operating costs.

Despite these challenges, two companies are operating commercial units that capture CO_2 from the air. Both companies require relatively low-cost zero-carbon power ($0.03–0.04/kW-hr) to achieve their current operating prices and performance.

• Climeworks, Zurich: A small Swiss company, Climeworks, has created the first commercial, for-profit direct air capture project. They have developed a robust, modular technology that capture 50 tons CO_2 /year, and have assembled 18 modules that sell 900 tons/year of CO_2 to an organic greenhouse. Climeworks technology delivers food-grade CO_2 in one step, as well as two tons of water for every ton of CO_2 capture. This technology is born mass-producible, scalable, and robust.

• Carbon Engineering, Vancouver: A small, Canadian company, Carbon Engineering has assembled and innovated around existing commercial components to make a new system (like the Wright brothers building a plane out of bicylcle parts). They deliver lower purity CO_2 than Climeworks, but appear to have susbtantially lower capital and operating costs.

Direct air capture can be deployed anywhere there is cheap, zero-carbon power. This creates a market value of avoided costs (e.g., no trucking or shipping). Early applications are likely to be in the food and carbonated beverage industry. It is also possible that they could sell CO_2 for EOR in locations where CO_2 supply is a challenge.

Question 7. Do you think there is scaling feasibility for ocean direct air capture technologies to pull CO_2 from the ocean to precipitate carbonate building materials like limestone bricks or sand? Could the act of pulling CO_2 from seawater indirectly aid in our solutions for ocean acidification?

Response. The cost of LLNL's ocean CO_2 capture system has not been established, and will require full scale demonstration of the sort being done in the air capture systems today. The advantage of our concept is that the ocean concentrates CO_2 due to biological activity, so we anticipate that we can improve on the cost of air capture systems. However, this is a fairly small difference, and capture from the ocean will still be more expensive than capture from any of the industrial sources we discussed above. It will, however, remediate some ocean acidification and of course the new advantage of the approach is that it will create new construction material in remote places. To be clear, we see direct ocean capture as providing both a new option and new benefit, and do not wish to criticize other air capture methods .

It is difficult to speak authoritatively to scaling of a system like this, but our thought process is to design a system that runs entirely on wind (preferred for cost and availability), wave, or solar power. Those costs we know well today. Our system will most likely require a location where tidal currents bring fresh seawater to the extraction process. This is a cost advantage because those flows are predictable. The value of the created building material must be high, favoring distant islands or places like Japan—industrialized countries that lack those specific resources. Onshore use is likely to be less economic than simple truck-transport of building materials.

The seawater exiting the process will be less acidic than the inlet. We anticipate that about 17,000 cubic meters will need to be processed to obtain one ton of CO_2 and two tons of calcium carbonate building material. That seawater will have a pH 0.1 pH units higher than the inlet, which would be a major factor for shellfish larvae which require high pH to make their first shells. Problems that may occur include clogging of the system by sea life (a constant problem for ocean water systems). We do not yet have an understanding of that difficulty.

Regarding the feasibility of scaling, we think the chances are good. The ancillary benefits of more building material and less acidification will only increase as the system is deployed at larger scale. As with any new idea, there may be problems that only are exposed by demonstration and testing. We look forward to an opportunity to do that. c. In addition to paying direct air capture a carbon payment for their avoided emissions, like we do in our recently introduced bipartisan CCUS bill. What else can legislators to drive these technologies closer to commercialization?

Systems such as the California Low Carbon Fuel System (LCFS) encourage rapid technology development. R&D on capture not from coal fired power is critical. Gas, industry, biofuel all need the kind of R&D that to date has been limited exclusively to coal by legislative language constraints. For the US Dept. of Energy to pilot and demonstrate those systems, amendment to appropriations language from the 2014, 2015, and 2016 budgets would be required.

Many potential policies could be considered. The most important and valuable policies would be ones which accomplish two goals. First, they should stimulate innovation for researchers and companies so as to improve performance and cost. Second, they should seek to create market pull for initial products and projects. Such policies could include tax incentives, grants, procurement requirements, product standards, feed-in-tarriffs, portfolio standards, and other policies to stimulate innovation and markets.

The U.S. carbon management science effort has been incredibly effective and leads the world, but is almost entirely focused on coal. We believe that natural gas for power and industry, biofuel production, and chemical reactions intrinsic to many industrial processes like steel making, now deserve the attention of the Nation's outstanding scientific resources. R&D in these areas will yield benefits immediately.

Fuels remain a major difficulty in U.S. carbon emissions. Two policies could help. 1) Encouragement of biofuel development and carbon management to reduce the carbon footprint of carbon fuels. 2) Encouragement of 'overshoot' CO_2 EOR where more CO_2 is used than is needed, effectively reducing the carbon footprint of the oil, would have a very similar effect for fossil fuel production (for example, with residual oil zone (ROZ) production).

These two approaches could be encouraged simultaneously by a single approach to low carbon fuels such as enhancing the Federal renewable fuel standard to encourage these approaches. That enhancement would improve the value of a RIN based on a better carbon footprint, encouraging both new processes as we have discussed, and overall efficiency in the production system. The California LCFS, with limited goals, has demonstrated how rapidly a process like this drives innovation. A similar change to RINs could have a nationwide effect, strongly improving the value of fuels made in America with forward-looking environmentally friendly processing.

In the longer term, the management of CO_2 in our economy requires a new paradigm which we think of as the carbon economy. CO_2 can be a feedstock, along with natural gas, for most of our industrial chemicals and fuels. The US has rich carbon resources and nearly unlimited renewable power which can create the new carbon economy and all the jobs and industries it entails. Investment at all levels of science and engineering will encourage this result—one we need to have in place by roughly 2050 to have any hope of meeting 2〉C. Our renewable revolution took that much time and a major investment of government and academic science, as well as many thoughtful policies to support the creation of new businesses to implement that science.

4. Emissions Free Grid by 2050:

Each witness from the hearing discussed different clean air technologies that if developed and commercialized can reduce our emissions footprint. There is international agreement that CCUS and other renewable technologies can play a role in helping us cut emissions consistent with meeting our 2C targets, in a way that is sustainable and economically sound.

a. Why are your labs prioritizing research in clean energy technologies like this?

As part of our missions for science in public service and to prevent and mitigate national security threats, we believe an emissions-free grid is both necessary and feasible. Investments over the last 20 years have made remarkable progress possible—wind and solar are now are the cheapest sources of power. Carbon capture and storage is demonstrated and safe. The investments in research have demonstrated their value. b. What role will advanced nuclear and carbon capture and utilization play in helping us meet our climate targets and having an emissions free grid by 2050?

Costs are now driving utility's choices in power production technology. The biggest gap in the present low-cost technologies is that renewables need something like storage or another zero-carbon source to make up their shortfalls when the wind and sun are not available. Today gas fills that role, but a zero-carbon electric system requires either massive storage with no gas, or CCS on gas. CCS on gas is possible today, and deserves the attention of policymakers. The U.S. vast reserves of natural gas can play a key role in electric power and hydrogen for industry, with thoughtful application of CCS.

The existing fleet of nuclear plants are an irreplaceable resource for carbon-free electricity. Along with hydro they simply make it easier to meet our other goals, which ultimately are driven by capital costs. Where will the Nation get the capital to build the power fleet we want? Many of our choices will take advantage of existing power infrastructure. While we are hopeful for advanced nuclear technology, it does not yet appear to have a cost structure that will enable it to penetrate the U.S. market. In particular, the two challenges of high capital costs of contruction and robust and swift licensing require more focused work to overcome these challenges.

Utilization will play the same role in the future that recycling does today in reducing waste. Once the technologies are available, industries will choose to treat CO_2 as a feedstock. Cheap renewable power will make this possible, and the ability to make products onsite in small inexpensive reactors instead of at massive refineries half the world away will open new possibilities for business to be efficient and flexible.

An immediate benefit of utilization technologies is as an energy storage mechanism. Both methane and transportation fuels can be made at any time and stored for almost nothing. With appropriate S&T to make those transformations affordable, this can be an excellent way to store our bounty of renewable energy, without the large capital investment required for battery storage.

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 8 months ORNL announced two remarkable breakthroughs in carbon capture and conversion. We discovered a simple, reliable process to capture CO_2 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 CO_2 and forms a crystal. The CO_2 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 CO_2 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 CO_2 and energy. Our scientists have used isotopes and tracers to decipher how CO_2 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 CO_2 .

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 1940's.

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 2030's. 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:]

Developing and Deploying
Advanced Clean Energy Technologies

Statement of Mohammad A. Khaleel, Ph.D.
Associate Laboratory Director, Oak Ridge National Laboratory

Before the
Subcommittee on Clean Air and Nuclear Safety
Committee on Environment and Public Works
U.S. Senate

July 25, 2017

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

INTRODUCTION

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

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

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

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

atom by atom —and we leverage ORNL assets such as Titan and the Center for Nanophase Materials Science for breakthrough materials research;
- Neutrons—We operate two of the world's leading neutron sources that enable scientists and engineers to gain new insights into materials and biological systems;
- Nuclear—We advance the scientific basis for 21st century nuclear fission and fusion technologies and systems, and we produce isotopes for research, industry, and medicine.

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

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

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

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

BENEFITS OF CLEAN, RELIABLE ENERGY

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

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

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

ORNL ADVANCES CLEAN ENERGY SCIENCE AND TECHNOLOGY

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

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

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

Carbon Capture, Utilization, and Sequestration

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

Capturing carbon from ambient air. ORNL researchers have discovered a new, low-cost method of capturing carbon directly from ambient air, offering a new option for carbon capture and storage that requires minimal energy and chemical input. The method uses a material that captures CO2 from the air and binds it as a crystalline carbonate salt. Releasing the carbon from the crystal for underground storage is accomplished through mild heating. Releasing carbon in traditional methods involves heating captured materials to extremely high temperatures to release the gas, a process that often emits more carbon than is removed from the atmosphere. Scientists are using the Spallation Neutron Source at ORNL to analyze the carbonate binding in the crystals with the aim of designing the next generation of sorbents.

Converting CO2 directly into ethanol. ORNL has developed a simple, efficient process to convert carbon dioxide directly into ethanol. The method uses a nanotechnology-based catalyst made from copper, carbon, and nitrogen, and applied voltage that triggers a chemical reaction. With the aid of the catalyst, we demonstrated a conversion to ethanol with a yield of 63 percent in the laboratory. The process operates at room temperature in water. In addition to removing carbon from the atmosphere, the process could be used to store excess electricity as ethanol. Doing so would help to balance a power grid supplied by intermittent renewable energy sources.

Fluid Interface Reactions, Structures and Transport (FIRST) Center. ORNL is leading FIRST, a DOE Energy Frontier Research Center, working with Argonne National Laboratory and seven universities across the nation to better understand how fluids and solids interact at the nanoscale to create new energy materials and processes. Understanding these interactions can advance new methods to convert CO2 to fuels.

Subsurface Science for Energy and the Environment

The subsurface is critical to the nation's low-carbon, secure energy future. The subsurface environment provides hundreds of years of safe storage capacity for CO2, and can serve as a reservoir for energy storage for power produced from intermittent generation sources such as wind and solar. ORNL R&D in this area encompasses:

Center for Nanoscale Controls of Geologic CO2. ORNL works in two areas for this DOE center:

- **Sealing effectiveness in shales.** ORNL is researching the basic science of seal resilience in CO2 leakage from below-ground carbon sequestration sites, determining which shale formations are ideal for secure storage.
- **Mesoscale modeling of the complex CO2-brine-mineral system.** We are helping develop advanced, more reliable and robust models to predict how quickly mineral reactions occur in response to CO2 sequestration—important for the long-term security of CO2 storage sites.

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

SubTER Program

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

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

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

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

Titan: Modeling Subsurface, Power Generation Applications

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

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

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

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

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

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

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

ARM Data Archive

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

"Big Ideas" for Carbon Utilization

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

ORNL ADVANCES NUCLEAR POWER SCIENCE & TECHNOLOGY

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

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

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

The Next Generation of Nuclear Energy

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

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

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

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

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

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

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

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

Examples of CASL applications include:

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

A Science-Based Design and Licensing Approach

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

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

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

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

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

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

Modeling and Simulation, Materials Science, Advanced Manufacturing for Nuclear

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

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

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

Advanced Reactor Research

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

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

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

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

CLOSING REMARKS

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

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

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

RESPONSES OF MOE KHALEEL TO ADDITIONAL QUESTIONS FROM SENATOR BARRASSO

Question 1. For each of the following countries, would you please provide a list of the advanced, non-light water reactor designs either under construction or operating: United States, China, and Russia.

Response. The following information is from the World Nuclear Association with regards to non-light water reactors currently operating or under construction.

United States:

None.

China:

A high temperature reactor (HTR) was built in China and wpent operational in 2003 after achieving its first criticality in 2000. China is also developing a high temperature gas reactor (HTGR) that began construction in 2012 and is expected to be connected to the grid by the end of 2017. China is currently marketing its HTGR technology and has recently signed a cooperative agreement with Saudi Arabia. China also has a sodium-cooled fast neutron reactor, the Chinese Experimental Fast Reactor that started operation in July 2010 and was built in cooperation with various Russian institutes. Although this reactor was connected to the grid in 2011, it has been operated sporadically since that time. China has signed additional agreements with Russia to further develop larger-scale fast reactors.

Russia:

The BN series of reactors at the Beloyarsk Nuclear Power Station in Russia are fast breeder reactors that support the use of a closed nuclear fuel cycle with mixed oxide fuels. Over recent decades, Russia has consistently invested in the development of breeder reactor technologies. Two are currently operating at the Beloyarsk site. Russia is also pursuing a number of fast reactor demonstration projects. These include the SVBR (Svintsovo-VIsmutovyi Bystryi Reaktor) 100 MWe, Pb-Bi cooled fast reactor, the BREST (Bystryi Reactor so Svintsovym Teplonositelem) 300 MWe, Pb-cooled fast reactor, and the multipurpose fast research reactor, MBIR, rated at 150 MWt.

Question 2. S. 512 contains robust provisions directing the Nuclear Regulatory Commission to develop a regulatory framework for licensing advanced reactors. What more can be done to improve the regulatory environment for advanced reactors in addition to enacting these provisions into law?

Response. In addition to examining licensing process options such as the staged licensing discussed in the bill, it is imperative that the Nuclear Regulatory Commission (NRC) undertake efforts to modify its licensing infrastructure to accommodate the licensing of advanced reactors. The first step in this process at the top level is underway with the NRC's issuance of a draft regulatory guide (RG) on the development of design criteria for advanced reactors. These criteria are derived from 10 CFR 50 Appendix A, and they are essentially light water reactor (LWR)-centric. This work resulted from a collaboration between the NRC and the Department of Energy (DOE) in which DOE laboratories drafted a proposed set of design criteria and provided them to the NRC for their consideration.

Equivalent versions of the NRC's Standard Review Plan (NUREG–0800) for LWRs are needed for liquid-metal, gas-cooled, and molten salt reactors to provide guidance to NRC staff on how to review license applications and potential licensees. The next level of documents that underpin the NRC Standard Review Plan are regulatory guides (RGs). These RGs must be reviewed to identify guidance that must be adapted for the various advanced reactor types to determine what, if any, new RGs might be needed. The RGs in many instances endorse national consensus standards as a means of meeting NRC requirements. DOE could take the lead responsibility to work with standards organizations to identify and support the development of needed standards for advanced reactors.

In summary, it is important to understand: (1) the relationships and dependencies of the several document types noted above that form the licensing infrastructure, and (2) that efforts need to start now for the NRC to be prepared to license advanced reactors. The NRC can license by exception, but that approach will likely be quite costly and would lack certainty for potential licensees.

Question 3. What more could DOE be doing to accelerate the development of Small Modular Reactors and demonstrate their ability to provide secure and highly reliable power for DOE and DOD national security and mission critical activities?

Response. DOE could accelerate development of small modular reactors (SMRs) by fulfilling the role as a "first mover" by deploying SMRs selectively across the US. In this role, DOE would assist in development of the supply chain that is critical to the success of any new reactor type. The supply chain provides jobs and re-establishes the needed commercial nuclear infrastructure. This effort would also support future deployment of advanced reactor technologies. Oak Ridge National Laboratory (ORNL) has conducted studies identifying small regional areas or clusters where the combined power needs of governmental agencies—largely driven by Department of Defense (DoD) military sites—match very well with electrical generation power capacities of SMRs. Early deployments would provide the SMR community with the needed opportunity to demonstrate their reliable, safe operations, which in turn could result in follow-on deployments in the US and internationally.

An additional area that could be addressed relates to the implications of having a limited number of personnel operating two or more reactor units. One of the prime cost savings areas associated with SMRs is based on the ability to limit the number of control centers for a suite of reactor units. However, the operational processes and challenges have yet to be fully examined and could be an area of contention in the licensing process. In addition, DOE could support efforts to develop the scientific basis for evaluating the passive safety systems and the main criteria that the NRC would need to consider for evaluating these systems. Appendix K of 10 CFR 50 is currently being used to establish the regulatory requirements for the emergency core coolant systems based on active cooling, whereas some SMR designs rely on passive cooling systems.

In addition to LWR SMR designs, several non-LWR SMR designs are being considered under advanced reactor concepts. Several companies are designing advanced SMRs around molten salt, sodium cooled, and HTGR technologies. DOE's research and development efforts in areas such as new materials for extreme environments, predictive modeling and simulation, and regulatory approaches are important for enabling the deployment of such technologies.

Question 4. What can the labs do to help make sure that Small Modular Reactors can be manufactured and constructed with the most advanced methods?

Response. National laboratories provide the fundamental scientific knowledge for the application, development, and demonstration of nuclear science and technology. Modular construction techniques have been perfected for the design of nuclear powered submarines and ships. Knolls Atomic Power Laboratory and Bettis Atomic Power Laboratory have been instrumental in the design process for the US Nuclear Navy.

An appropriate role for national labs, like ORNL for example, may be to establish component prototyping centers using capabilities in materials, neutrons, and modeling and simulations at exascale to develop and deploy innovative manufacturing technologies, where advanced manufacturing and 3D printing at DOE's Manufacturing Demonstration Facility can be used to design, print, and test reasonably sized components in representative experimental facilities. These efforts would be followed by design modifications as needed. Related activities are being performed at DOE facilities today under programs through the Advanced Manufacturing Office within DOE's Office of Energy Efficiency and Renewable Energy. New materials and processes have been demonstrated for first-of-a-kind products at ORNL, such as wind turbine forms, pressure hulls for small submersibles, and large-scale excavating equipment. Such an approach for nuclear manufacturing could help shorten the time to develop and qualify components, thus reducing costs and time to commercialization.

Question 5. Industry, the national labs, and the Nuclear Regulatory Commission need employees with specialized skill sets in nuclear-related disciplines to accomplish their missions. Is enough being done to ensure universities produce adequate numbers of graduates in these fields?

Response. Currently, Federal agencies provide direct support to nuclear engineering programs through NRC, DOE and the National Nuclear Security Administration (NNSA). Congress has generously appropriated funding to each of these organizations to support US university programs. In addition, the DOE Office of Nuclear Energy (DOE-NE) also allocates a portion of its research and development budget to the university program through competitive grants that support the DOE-NE mission. These efforts have helped sustain and maintain interest in nuclear science and technology.

As an example, this program could be modeled after the DOE's NNSA Nuclear Security Education Program to establish a graduate-level program to develop and educate the next generation of engineers with careers in the nuclear fields.

In addition, consideration should be given to funding focused internships at DOE labs, the NRC, utilities operating commercial nuclear plants, and reactor design developers. Industry-national lab-university focused advisory councils provide unique opportunities to inform stakeholders of the barriers and challenges facing the nuclear energy sector. The goal is to create visibility and enthusiasm among students while better preparing them for the nuclear energy job market.

RESPONSES OF MOE KHALEEL TO ADDITIONAL QUESTIONS FROM SENATOR SHELDON WHITEHOUSE

1. CCUS TECHNOLOGIES GENERAL:

During the hearing, I mentioned several CCUS projects that have come online in recent years. This includes the Iceland Carbfix Program, the Climeworks Direct Air Capture facility in Switzerland, the BioProcess H2O ethanol facility, and the Boundary Dam III carbon capture facility in the Canadian Province of Saskatchewan. These facilities cover a broad variety of CCUS technologies that includes coal, ethanol, permanent sequestration, and direct air capture.

Question 1. Can you discuss the other promising CCUS technologies that have come online in recent years either at the pilot scale or larger? What are the economics of these projects that allow them to operate?

Response. Our understanding is that many carbon capture technologies have been demonstrated at pre-production scales, but additional research and testing is required to validate long term and commercial scale viability of the various approaches. Many recent pilot scale efforts have involved solvent, sorbent, and membrane separation technologies, but key limitations have yet to be resolved.

For example, the energy costs for process steps such as regeneration or desorption of solvent and sorption must be addressed through additional research and development (R&D). Membrane technologies must address significant technical challenges such as throughput enhancement and fouling mitigation. ORNL is developing high-throughput, polymer-based membranes that may overcome existing barriers. Finally, there are earlier stage separation approaches, such as chemical looping combustion, that hold promise but require experimentation before they can be implemented at the scales needed for carbon capture, utilization, and storage (CCUS).

There is a strong need for a large-scale (ideally gigatons of CO2) geologic sequestration demonstration in the United States. One project not mentioned above that we are familiar with is the Nagaoka CO2 storage project, in Nagaoka, Japan. From 2003 to 2005, 10,499 tonnes of CO2 was injected into an onshore deep oil and gas reservoir and CO_2 plume migration and its reaction with the surrounding rock are currently being monitored.

The CO_2 was from ammonia production, and was transported to the site by truck. The cost was approximately $67 per tonne of CO_2 sequestered, including separation/capture pressurization (57 percent of cost), transport (11 percent of cost), and injection (32 percent of cost). Economic analysis found that cost reductions need to occur in the separations and capture processes, that utilization of reservoirs near emissions sources reduced costs significantly, and that injection capacity should be increased.

The DOE Energy Frontier Research Center for Nanoscale Controls of Geologic CO_2 made the study site a focus of its research to examine the capacity to precipitate CO_2 in the form of carbonate minerals, helping to determine the long term storage security of the CO_2 . Researchers found evidence for substantial reaction with volcanogenic minerals in the rock, suggesting that storage security would be high because CO_2 would be immobilized in mineral phases.

An example of a recent carbon utilization project is in the city of Saga, Japan. There, Toshiba Corporation completed a system in August 2016 to capture up to 10 tons of CO_2 per day from flue gas at a municipal waste incineration plant. The technology was originally developed for cabon capture at power generation plants.

Saga has constructed a pipeline to deliver the captured CO_2 to an adjacent facility where it is used in algae cultivation. The algae is then used to produce raw materials for cosmetics and nutritional supplements. Utilizing the CO_2 supply in a process to make aviation biofuels from algae is also being studied. The Saga carbon capture and utilization project was estimated to cost approximately US$15 million.

Question 2. Can you also discuss what CCUS technologies you believe could be coming online over the next several years as it relates to both CCUS and direct air capture?

What types of CCUS technologies hold the most promise as it relates to reducing our emissions to address climate change?

Response. These two questions have some similarities, so I will address them together.

Use of captured CO_2 for enhanced oil recovery (EOR) holds promise because there is an economic incentive to utilize the CO_2 . However, beyond developing efficient carbon capture technologies, establishing the long-term fate and transport of the CO_2 and its storage security is necessary if EOR is to be used for sequestration, as opposed to production.

About 80 percent, or 9 million metric tons of captured CO_2 used by industry is in enhanced oil and coal-bed methane recovery operations. Estimated net marginal value for CO_2 in EOR varies widely with oil price and field conditions. According to one 2014 estimate, the value one would be willing to pay to have CO_2 delivered at a field varies between approximately 5/tCO_2 to $66/t$CO_2$, with the highest values applying in times of high oil price. Another estimate ranges US $4/t$CO_2$ to $8/t$CO_2$.

Direct air capture (DAC) of CO_2 is an attractive CCUS technology as it could be employed anywhere and would not be subject to fouling by contaminants such as sulfur oxide and nitrogen oxide often present in smokestacks. The process could provide a ready feedstock of CO_2 for utilization technologies such as fuel production.

Researchers are currently focused on chemical sorbents that can effectively remove CO_2 at low concentrations in the atmosphere—including calcium hydroxide, which binds with CO_2 to form calcium carbonate. However, the process to separate out the captured CO_2 from the calcium carbonate for utilization or storage is currently considered too energy-intensive and inefficient. Other proposed approaches include mineral carbonation and electrochemical processes, the use of membranes, and photocatalytic CO_2 conversion. All require further exploration.

As an example, our ORNL scientists discovered a low-cost method of DAC that requires minimal energy and chemical input. The method uses a simple compound known as guanidine that captures CO_2 from the air and binds it as a crystalline carbonate salt. Releasing the carbon from the crystal is accomplished through mild heating. While the findings are promising, more R&D is needed to explore and potentially scale up the process. Our scientists are using the Spallation Neutron Source at ORNL to analyze the carbonate binding in the crystals with the aim of designing a next generation of sorbents.

2. CARBON UTILIZATION:

To address climate change, we must reduce our emissions from multiple sectors, including the power, industrial sector, and transportation sector. As discussed during the hearing, BioProcess H2O is unique as it reduces emissions from an ethanol plant.

Question 3. What are the different forms of carbon utilization that have proven to work at the pilot scale? In your opinion what are the promising carbon utilization technologies that have not yet been tested at the commercial scale?

Response. Carbon utilization can be divided into four broad categories: direct utilization, biological utilization, geologic utilization, and chemical utilization. CO2 utilization remains a challenge due to both the life-cycle energy considerations and the potential requirements for the CO2 stream (such as purity).

Current commercial direct uses of CO_2 include processes for carbonation for beverages, and as a supercritical solvent. The magnitude of these uses is stable and small relative to carbon emissions.

Biological utilization of enriched CO_2 stream has been demonstrated with algae at pilot scale and beyond. Several companies are pursuing and selling products in high-value arenas such as for feed. However, challenges remain to lower costs and improve yields for fuels and commodity chemicals.

While geological utilization for enhanced oil recovery is demonstrated, more long-term research on the fate of CO_2 pumped belowground is needed. Chemical utilization is mostly at the pre-pilot scale to convert CO_2 into chemicals such as carbon monoxide or hydrocarbons using renewable heat, light, and electricity.

The biological, electrochemical, photochemical and various hybrid combinations are promising approaches that would require more R&D, including demonstrations. For example, at ORNL we have developed a simple, efficient process to convert CO_2 directly into ethanol. The method uses a nanotechnology-based catalyst made from copper, carbon, and nitrogen, and applied voltage that triggers a chemical reaction. With the aid of the catalyst, we demonstrated a conversion to ethanol with a yield of 63 percent in the laboratory. The process operates at room temperature in water. In addition to removing carbon from the atmosphere, the process could be used to store excess electricity as ethanol. Doing so would help to balance a power grid supplied by intermittent renewable energy sources. This laboratory-scale process also needs further R&D to be proven effective at a larger scale, however.

The Carbon X-Prize provides an excellent cross-section of CO_2 utilization technologies in early commercial development by 23 teams from six countries. These teams are pushing the boundaries of CO_2 utilization to create breakthrough solutions to turn waste (CO_2 emissions) into valuable products such as fish food, fertilizer, carbon nanotubes, and building material. The teams are listed at http://carbon.xprize.org/teams.

Question 4. What does carbon utilization mean for the overall economics of making CCUS projects more cost competitive?

Can carbon utilization play a major role in reducing the cost of capture for CCUS projects?

Response. These two questions have some similarities, so I will address them together.

According to both the International Energy Agency and the Intergovernmental Panel on Climate Change (IPCC), CCUS can play a critical role in emissions reduction. It is unlikely that key industrial sources, which generate approximately 20 percent of greenhouse gas emissions, can be decarbonized without CCUS. However, CCUS is a capital-intensive enterprise that has not fully advanced to the point of broad commercialization.

Carbon utilization (CU) can help with the economics of CCUS in any case where the utilization value of CO_2 minus the transportation cost to the point of use is positive. In that case it can defray the cost of capture and avoid the cost of sequestration or emission. A range of advanced CU concepts are being evaluated, including conversion of CO_2 to fuels, chemicals, and building materials.

It is important to recognize that in terms of CO_2 emissions, CCU is not a one-for-one substitute for CCS because the utilized CO_2 might eventually be re-emitted to the atmosphere. However, a carbon atom that is captured and reused can replace a carbon atom from fossil sources, thereby limiting total emissions. Life-cycle analysis of energy use and emissions is important to the comparative economics of carbon utilization.

3. EMISSIONS FREE GRID BY 2050:

Each witness from the hearing discussed different clean air technologies that if developed and commercialized can reduce our emissions footprint. There is international agreement that CCUS and other renewable technologies can play a role in helping us cut emissions, in a way that is sustainable and economically sound.

Question 5. Why are your labs prioritizing research in clean energy technologies like this?

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

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

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

Through these activities—conducted at large scales and with significant, long-term investments of resources, including world-class scientific and technical expertise—DOE's national laboratory enterprise serves as an enduring science and technology powerhouse for the Nation.

Question 6. What role will advanced nuclear and carbon capture and utilization play in helping us meet our climate targets and having an emissions free grid by 2050?

Response. The United States cannot have an emissions-free grid by 2050 without increased use of nuclear energy and commercialization of effective carbon capture technologies. Carbon emissions cannot be eliminated through use of wind, solar, and other renewable sources alone.

Advanced nuclear reactor concepts offer significant potential advantages relative to current light water reactor technology in terms of improved safety, cost, performance, sustainability, and reduced proliferation risks. DOE has recently stated that by 2050, advanced reactors will provide a significant and growing component of the nuclear energy mix both domestically and globally, due to advantages in terms of improved safety, cost, performance, sustainability, and reduced risk of proliferation.

Nuclear energy, which currently accounts for more than 60 percent of carbon-free electricity production in the United States, can be expected to grow even more with the introduction of advanced reactor technology.

Carbon capture and utilization (CCU) is also expected to contribute to reducing emissions of greenhouse gases from various industrial and manufacturing sectors, although the main benefits likely to be derived from CCU lie in offsetting the use of petroleum products in the production of transportation fuels, chemicals, and high-value products that would otherwise be derived from petrochemical feedstocks. The current global demand for chemicals does not have the capacity to sequester enough CO2 emissions to contribute significantly to meeting carbon reduction targets.

4. ADVANCED REACTORS AND MODEL SIMULATIONS:

Dr. Khaleel, you discussed several modeling tools used in nuclear research in your testimony, this includes CASL and the Virtual Environment for Reactor Development (VERA). You stated that CASL was used to simulate 14 cycles (20 years) of the TVA Watts Bar Unit 1 and operations and simulation of Watts Bar Unit 2 start-up. Other uses included modeling and simulation for accident tolerant fuels and use in advanced reactor research.

Question 7. Can you discuss whether these modeling tools should be used in the development and potential licensing of non-light water reactors?

Response. Modeling and simulation tools that are applicable to advanced non-LWRs are essential for supporting concept development, reactor design, reactor safety analysis, regulation, and licensing. The primary driver for this need is the limited operational and experimental data available for advanced concepts—particularly in comparison to the mature LWR industry. Most available advanced reactor data resulted from the US reactor development programs in the 1950's through the 1980's. Development of additional required data is difficult due to the lack of test reactor facilities and the significant time and expense required. Therefore, modeling and simulation is crucial to supplement the historical data, to make the best use of current experimental programs, and to optimize future experimental programs.

Many modeling tools for advanced reactors are relatively old and do not conform to modern software practices. Furthermore, these tools do not take advantage of the significant advances in computing. The capabilities being developed in VERA under the Consortium for Advanced Simulation of Light Water Reactors (CASL) are for LWRs, but their basis allows them to be extended to non-LWRs. In addition, DOE-NE also established the Nuclear Energy Advanced Modeling and Simulation (NEAMS) program to develop modeling capabilities for non-LWRs. NEAMS has mostly focused its multiyear development efforts on high-fidelity simulations for sodium fast reactors, but a planned consolidation of CASL and NEAMS offers an opportunity for DOE to leverage tools from both programs and expand these capabilities to support numerous reactor types. Engagement with companies developing advanced reactor concepts through the Gateway for Accelerated Innovation in Nuclear has also established the need to develop new modeling capabilities to support their activities.

Question 8. Is there a role for modeling simulations for licensing of advanced reactors, for testing different materials that may be more resistant to radiation?

Response. The licensing of advanced reactors relies on modeling to perform the required safety analysis to understand the performance of the reactors in normal and postulated off normal conditions. Typically, this analysis is performed by the reactor designer, and the regulator may perform a confirmatory analysis as part of its review processes. In "NRC Vision and Strategy: Safely Achieving Effective and Efficient Non-Light Water Reactor Mission Readiness," the NRC has stipulated that "staff must have adequate computer models and other analytics resources to conduct its review of non-LWR designs in an independent manner."

Modeling supports development of new materials in several ways, including fundamental atomistic simulations of materials in the appropriate environments (radiation, temperature, etc.) to investigate performance and to identify promising materials. Modeling also supports experimental irradiations used to test the materials by simulating test reactor conditions to ensure that the experiments will meet the test objectives. Modeling is also used to extrapolate and compare performance of materials under test conditions to performance in an actual reactor, which may scale to longer periods of time, such as throughout the entire 40-to 60-year expected reactor lifetimes.

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 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 2 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:]

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Kemal Pasamehmetoglu,
Associate Laboratory Director, Nuclear Science & Technology
Idaho National Laboratory

Developing and Deploying Advanced Clean Energy Technologies
Subcommittee on Clean Air and Nuclear Safety
U.S. Senate Committee on Environment and Public Works

Introduction

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

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

The Value Proposition for Advanced Nuclear Energy Technologies

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

In the U.S., the current light-water reactor fleet has been the workhorse of emission-free baseload electricity generation at approximately 100 GWe capacity. Nuclear energy currently provides approximately 19 percent of total electricity and 63 percent of our national electricity sector's carbon-free generation today without emitting air pollutants during operations. Nuclear energy's contribution to our national electricity generation

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and air quality must be maintained and, with advanced nuclear technologies on the near-term horizon, grow into the future.

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

Opportunities

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

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

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

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

Challenges

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

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

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

Mission

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

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

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

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

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Vision

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

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

Nuclear Energy Technologies: The Paths Forward

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

Small Modular Reactors

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

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

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

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

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

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

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

Advanced Non-Light-Water Reactor Technologies

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

The next generation of reactors will provide enhanced passive safety features, while increasing efficiency, expanding applications and reducing environmental impact. They

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will need to be economical and reduce proliferation risk. These aspects require accelerated innovation in order to achieve commercialization of SMRs and advanced reactors in a timely manner.

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

Advanced reactor technologies offer key performance features such as:

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

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

Gateway for Accelerated Innovation in Nuclear

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

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

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

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

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

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

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

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

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

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

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

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

Developing and Deploying Advanced Nuclear Energy Technologies

Kemal Pasamehmetoglu,
Associate Laboratory Director, Nuclear Science & Technology
Idaho National Laboratory

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

Summary

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

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

The U.S. will continue to research various scenarios. One considered scenario includes the vision of doubling the national nuclear energy capacity to 200 GWe between now and 2050. Under that scenario, we will see today's light-water reactors, SMRs, and advanced non-light-water reactors operating side-by-side. The assessment of that scenario also highlights the sense of urgency associated with developing the supply-chain and initial deployment of the advanced reactor prototypes. There is an urgent need to develop and deploy significant new and flexible nuclear energy capacity,

Developing and Deploying Advanced Nuclear Energy Technologies

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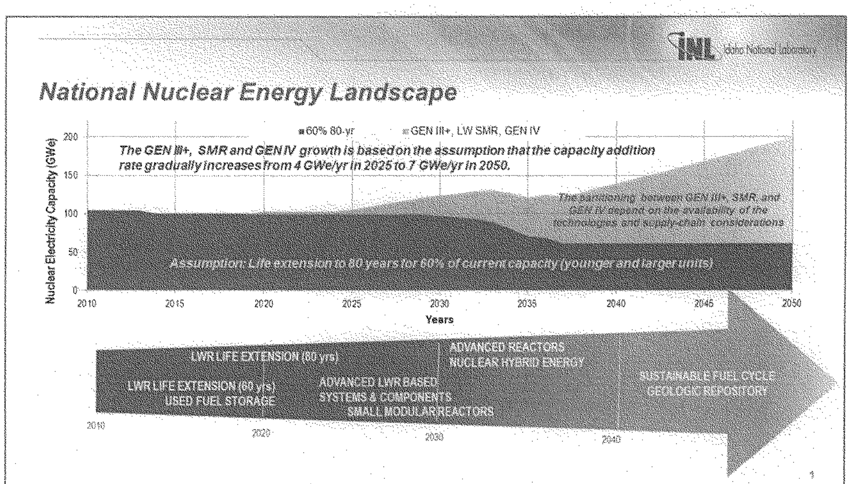
starting now and ramping up significantly in the 2030-2040 timeframe as our current reactor fleet approaches retirement. This time frame also is critical for U.S. to establish industrial leadership in the global markets. The following figure illustrates the notional scenario along with high-level timeline for critical milestones.

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

Notional Scenario



For More Information

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

RESPONSES OF KEMAL PASAMEHMETOGLU TO ADDITIONAL QUESTIONS FROM SENATOR BARRASSO

Question 1. For each of the following countries, would you please provide a list of the advanced, nonlight water reactor designs either under construction or operating: United States, China, and Russia.

Response.

United States: Under Construction:

None Operating: None

China: Under Construction: Shidaowan 1—High Temperature Gas Reactor (HTGR)

Operating: China Experimental Fast Reactor (CEFR)—Sodium-cooled Fast Breeder Reactor (FBR)

Russia: Under Construction: None

Operating: Beloyarsky–3 (BN–600)—Sodium-cooled FBR Beloyarsky–4 (BN–800)—Sodium-cooled FBR

Question 2. S. 512 contains robust provisions directing the Nuclear Regulatory Commission to develop a regulatory framework for licensing advanced reactors. What more can be done to improve the regulatory environment for advanced reactors in addition to enacting these provisions into law?

Response. S. 512's robust provisions are an excellent start toward the regulatory changes that need to be implemented in order to protect U.S. leadership in nuclear energy innovation. To further protect U.S. leadership, additional measures should be designed to accelerate the timeframe and mitigate the cost of bringing innovative advanced nuclear technologies through the technology and demonstration stages to prepare them for market. The time required for the licensing stages and the difficulty in navigating the multiple regulatory regimes for siting a new plant has already pushed some advanced reactor developers to consider building their demonstration/pilot plants in competing nations. A risk-based and staged licensing framework would be useful for facilitating investment decisions at different phases of advanced reactor development projects.

Question 3. What more could DOE be doing to accelerate the development of Small Modular Reactors and demonstrate their ability to provide secure and highly reliable power for DOE and DOD national security and mission critical activities?

Response. DOE can help accelerate the development of Small Modular Reactors (SMR) through policies and programs that will ensure the ability to resolve the First-Of-A-Kind (FOAK) engineering challenges that inevitably arise during the design and construction of these units.

New methods of implementing public/private partnerships, including assistance with siting, are a good first step. One such example exists with the UAMPS/NuScale project under way at the INL site. DOE's objectives to support innovative nuclear technologies require that these long-term projects are carried through to completion. Aggressive support of joint-use research and demonstration projects such as the Joint Use Module Project (JUMP) hybrid systems proposed for the NuScale reactor also helps overcome the financial hurdle for the construction and operations of FOAK units. In general, a combination of loan guarantees, tax credits, power-purchase agreements, government site use permits, and joint research arrangements for enhancing U.S. technology leadership are all tools that can be used to enable SMR (and advanced reactor) commercialization.

Question 4. What can the labs do to help make sure that Small Modular Reactors can be manufactured and constructed with the most advanced methods?

Response. Expanded use of the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative to support advanced manufacturing technologies aimed at construction of nuclear plant components and systems will help ensure plant construction can take advantage of the safety, cost, and quality control benefits of modular and modern manufacturing techniques.

Question 5. Industry, the national labs, and the Nuclear Regulatory Commission need employees with specialized skill sets in nuclear-related disciplines to accomplish their missions. Is enough being done to ensure universities produce adequate numbers of graduates in these fields?

Response. DOE and its national laboratories provide support for nuclear-related disciplines through various university partnership programs and direct support to universities with the Nuclear Energy University Program. In the last decade, these programs have been very useful in strengthening education in related areas, and both the laboratories and industries are benefiting from the human resources created under these programs. These programs must continue to ensure the transfer of critical knowledge and experience from the existing workforce, much of whom are nearing retirement, to new employees.

RESPONSES OF KEMAL PASAMEHMETOGLU TO ADDITIONAL QUESTIONS FROM SENATOR WHITEHOUSE

1. EMISSIONS FREE GRID BY 2050:

Question 1. Each witness from the hearing discussed different clean air technologies that if developed and commercialized can reduce our emissions footprint. There is international agreement that CCUS and other renewable technologies can play a role in helping us cut emissions consistent with meeting our 2C targets, in a way that is sustainable and economically sound.

Why are your labs prioritizing research in clean energy technologies like this?

Response. The scenarios analyzed under the 2C targets show that a single technology will not be sufficient to achieve the goals. An optimized combination of all the technologies, including CCUS and nuclear energy, will be needed. The economics and timing associated with the technology maturity will determine the relative contributions of these technologies to greenhouse gas reduction as we move forward. As such, the laboratories are working across the spectrum of these technologies, and not necessarily picking winners at this stage of the research.

Question 2. What role will advanced nuclear and carbon capture and utilization play in helping us meet our climate targets and having an emissions free grid by 2050?

Response. Both advanced nuclear and to a lesser extent, CCUS technologies will have a major role in achieving an emissions-free grid by 2050. Past and ongoing investments into the development of advanced nuclear technologies have laid the groundwork for the final stages of technology development and demonstration in the near term. These investments will help ensure that commercial-scale deployment is feasible as the bulk of the current light water reactor fleet begins to shut down as we approach 2050. The economics and timing associated with the technology maturity will determine the relative contributions of these technologies to greenhouse gas reduction as we move forward.

Question 3. Dr. Pasamehmetoglu in your testimony you said the stalemate on dealing with our nation's nuclear waste is more political than technical.

Can you elaborate on what is holding us back from dealing with our nation's waste stockpile?

Response. Extensive national and international studies indicate that we can engineer storage and disposal facilities to isolate used nuclear fuel and nuclear waste from the environment for many thousands of years. Engineering features depend on the choice of the repository location, but feasible solutions have been developed for a Yucca Mountain-like repository, salt formation repositories such as the Waste Isolation Pilot Plant (WIPP) in New Mexico, clay or granite repositories that have been studied abroad. My statement was predicated on our experience to date, where multiple Federal, State and local jurisdictions are involved in every aspect of evaluating, identifying, constructing and operating the sites. Such multi-layered, overlapping jurisdictions mean that any project, regardless of technical merit, can be effectively blocked or delayed at any stage through combinations of emotionbased 'not-in-my-backyard' activism and focused legal actions. Additionally, the long-term sustained effort needed to advance these projects is often derailed as a result of changes in political climate.

Question 4. Do you think there is value to working to develop advanced reactor concepts that can reuse our spent nuclear fuel? What are the biggest barriers for advancing these types of advanced reactor concepts? What role can these advanced concepts play in addressing our waste stockpile?

Response. Advanced reactor concepts that can reuse spent nuclear fuel have value in two key areas: (1) the ability to extract more useful energy from existing inventories of spent fuel with minimal processing (e.g., molten salt reactors) and (2) the ability of some advanced fast reactor technologies to eliminate the longest-lived transuranic elements from the waste stream can greatly reduce the complexity, size, and cost of the needed final disposal sites. The biggest barriers for advancing these reactor concepts are similar to those for advanced technologies in general, as mentioned above. As mentioned here, these concepts can play a significant role in reducing the volume and long-term radiotoxicity of waste for final disposition. At present, recycling technologies are not being pursued in the U.S. at commercial scale because of the economics of the associated reactors and recycling facilities. Recycling concepts exist with both improved economics and reduced environmental impact. Continued development and demonstration in this area will be beneficial for transitioning into a cost-effective recycling economy with the right kinds of reactors and with reduced environmental impact.

Question 5. Dr. Pasamehmetoglu, during the hearing several modeling tools used in nuclear testing and development were discussed, including CASL and the Virtual Environment for Reactor Development. It was also noted that next-generation materials that can withstand higher temperature and radiation environments are being developed and tested through computer modeling.

How accurate are these modeling tools?

Response. The capabilities of newer modeling platforms is expanding at a pace that closely follows the continuing advancements in high-performance computing technology, and it will continue to grow. Advances in computation, numerical analysis, and fundamental material science allow us to model phenomena with accuracy that was not possible even a decade ago. However, these multi-scale and multi-physics modeling tools need to be validated against experimental data. To make the tools truly predictive, novel multi-scale phenomenological experimental techniques are being used, and the data support the validation efforts. In some areas, these tools are already making a difference in the way we design fuels and additional, focused experiments to accelerate the development process (e.g., BISON/MARMOT fuel modeling code). Other areas of physics codes are catching up very rapidly as well. I believe that within a decade, a paradigm shift will occur in the way we use these predictive codes in accelerating the advancement of nuclear energy technologies.

Question 6. Is there a role for computer model simulations in the regulatory approval and licensing of advanced reactors?

Response. Computer model simulations have and will continue to have a role in the licensing of advanced reactors as modeling systems are developed and validated to simulate the many advanced concepts. As each new modeling system is tested with the appropriate level of experimental validation, regulatory and licensing authorities can begin to take advantage of these models to accelerate deployment of the technologies. Multi-scale, multi-physics codes designed to reduce uncertainty propagation will be very beneficial for developing risk-informed regulatory and licensing frameworks that will define adequate safety margins without excessive cumulative conservatism.

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 7-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.

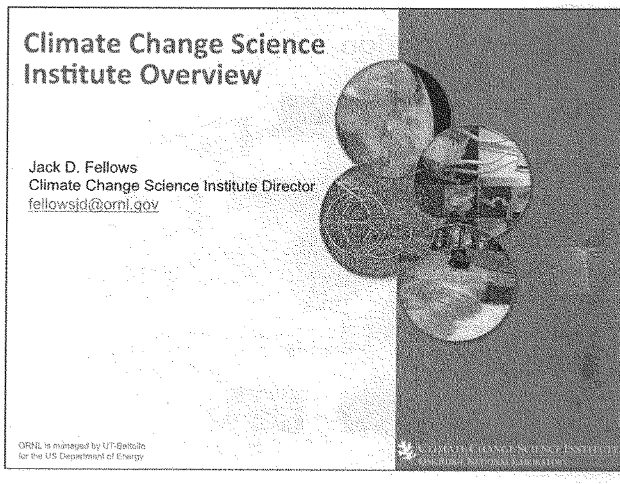
And, of course, our distinguished national laboratories appear to be unanimous in the view that climate science is serious.

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:]


Climate Change Science Institute Overview
Jack D. Fellows
Climate Change Science Institute Director
fellowsjd@ornl.gov
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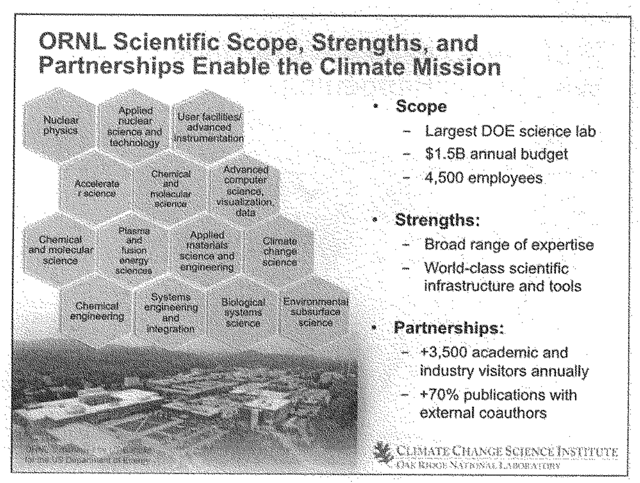
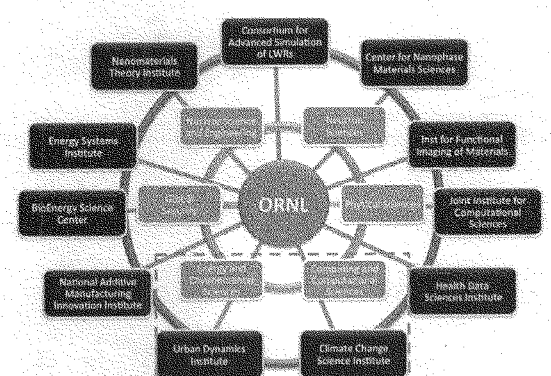
Climate Change Science Institute
Oak Ridge National Laboratory


ORNL Scientific Scope, Strengths, and Partnerships Enable the Climate Mission
Nuclear physics
Applied nuclear science and technology
User facilities/ advanced instrumentation
Accelerator science
Chemical and molecular science
Advanced computer science, visualization, data
Chemical and molecular science
Plasma and fusion energy sciences
Applied materials science and engineering
Climate change science
Chemical engineering
Systems engineering and integration
Biological systems science
Environmental subsurface science
• Scope
– Largest DOE science lab
– $1.5B annual budget
– 4,500 employees
• Strengths:
– Broad range of expertise
– World-class scientific infrastructure and tools
• Partnerships:
– +3,500 academic and industry visitors annually
– +70% publications with external coauthors
Climate Change Science Institute
Oak Ridge National Laboratory

ORNL Organization
Centers and Institutes



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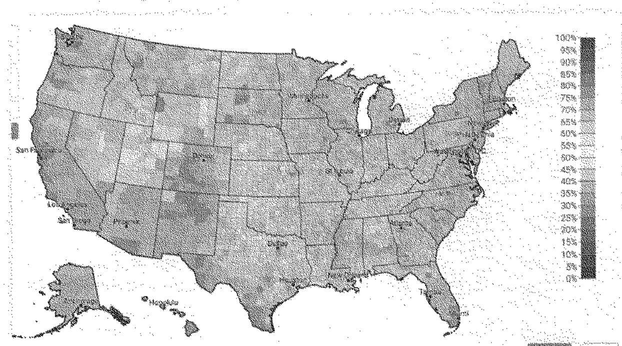
CLIMATE CHANGE SCIENCE INSTITUTE
OAK RIDGE NATIONAL LABORATORY

% of Adults in 2016 Who Think Global Warming is Happening



Source: Yale Climate Survey

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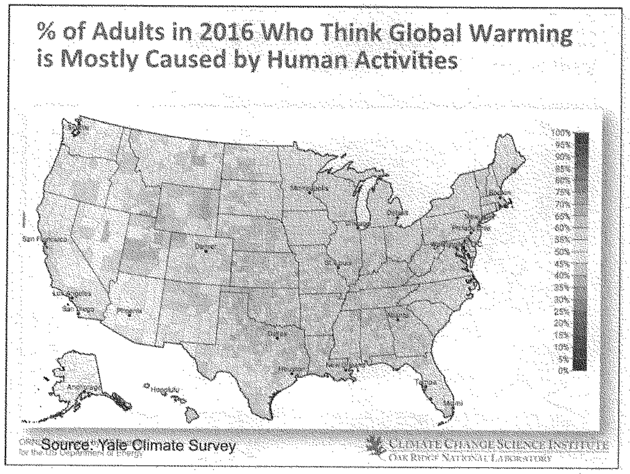
% of Adults in 2016 Who Think Global Warming is Mostly Caused by Human Activities
Source: Yale Climate Survey
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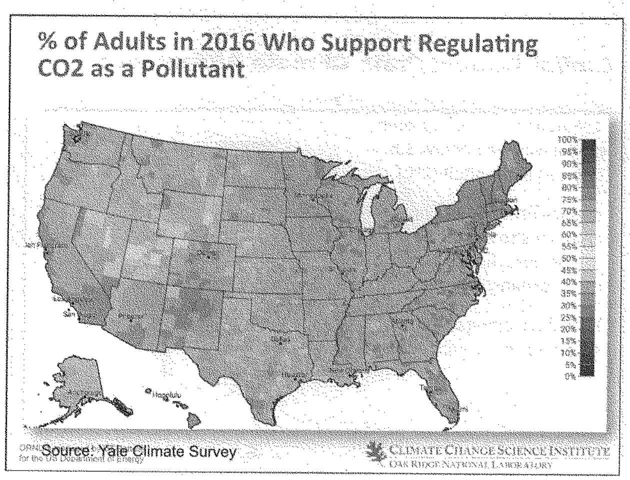
% of Adults in 2016 Who Support Regulating CO2 as a Pollutant
Source: Yale Climate Survey
CLIMATE CHANGE SCIENCE INSTITUTE
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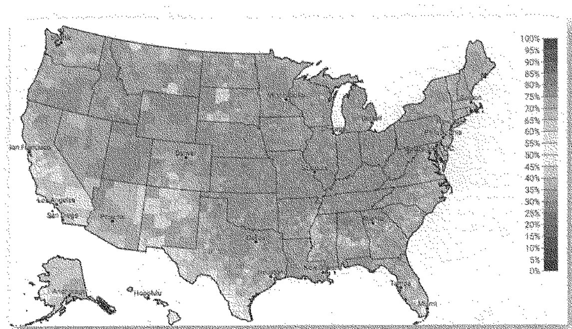
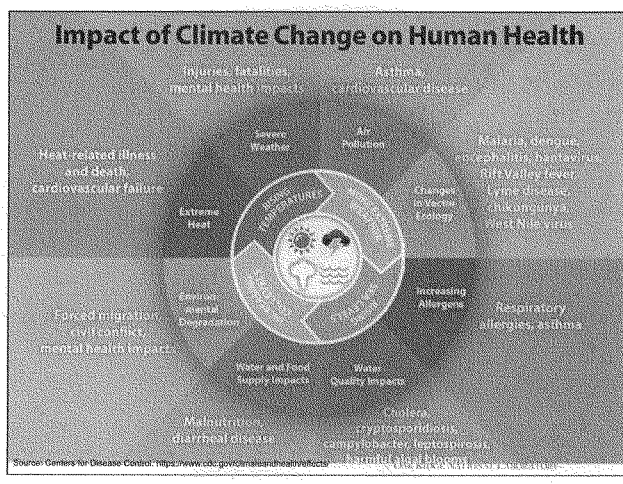
% of Adults in 2016 Who Think Global Warming Will Harm Them Personally

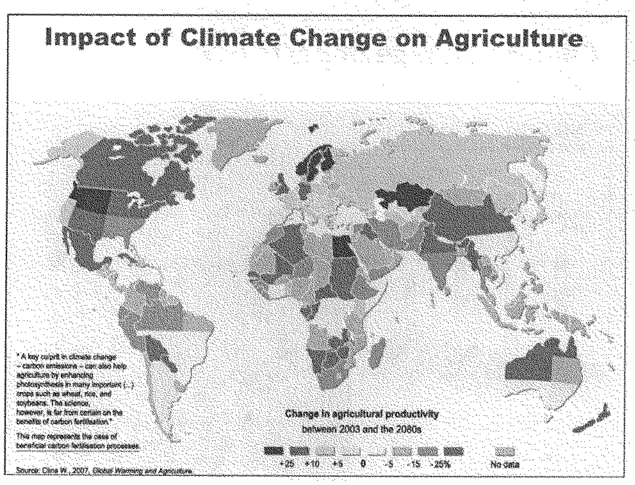


Source: Yale Climate Survey

Global Action: Paris Climate Agreement

- 195 nations agreed to keep global warming below 3.6 degrees Fahrenheit (2°C)
- Reduce greenhouse gas emissions to the levels that can be absorbed naturally by trees, oceans, and soils
- Help developing countries switch to renewable energy


Impact of Climate Change on Human Health
Injuries, fatalities, mental health impacts
Asthma, cardiovascular disease
Severe Weather
Air Pollution
Heat-related illness and death, cardiovascular failure
Malaria, dengue, encephalitis, hantavirus, Rift Valley fever, Lyme disease, chikungunya, West Nile virus
Extreme Heat
Changes in Vector Ecology
RISING TEMPERATURES
Increasing Allergens
Respiratory allergies, asthma
Environmental Degradation
Forced migration, civil conflict, mental health impacts
Water and Food Supply Impacts
Water Quality Impacts
Malnutrition, diarrheal disease
Cholera, cryptosporidiosis, campylobacter, leptospirosis, harmful algal blooms
Source: Centers for Disease Control: https://www.cdc.gov/climateandhealth/effects/


Impact of Climate Change on Agriculture
" A key culprit in climate change – carbon emissions – can also help agriculture by enhancing photosynthesis in many important (...) crops such as wheat, rice, and soybeans. The science, however, is far from certain on the benefits of carbon fertilisation."
This map represents the case of beneficial carbon fertilisation processes.
Change in agricultural productivity between 2003 and the 2080s
+25 +10 +5 0 -5 -15 -25%
No data
Source: Cline W., 2007, Global Warming and Agriculture.

Climate Change Impacts on Transportation Infrastructure

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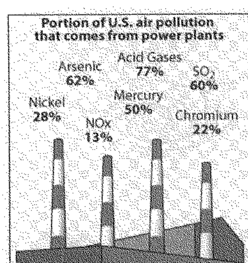
Climate Change Impacts of Air Quality



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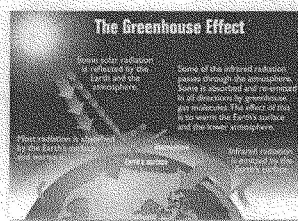
Greenhouse Effect

- When sunlight passes through the atmosphere it is absorbed by the Earth's surface and re-radiated back into the atmosphere at a different wavelength.
- Some of that radiation escapes back into space, but much of it is absorbed by greenhouse gases like carbon dioxide and methane.
- This mechanism is fully proven, and the Earth would be too cold for life without it.
- Current warming is consistent with amounts of greenhouse gases in the atmosphere



Source: EPA, 2012

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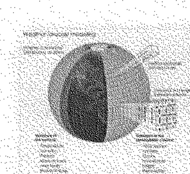
Weather vs. Climate

Weather Prediction. Driven by observations

- Daily variations of temperature and precipitation.
- Requires defining the atmosphere and ocean initial conditions from real-time observations.
- Quite accurate 3-5 days, but less so over time due to errors in initial condition that grow with time.
- Theoretical limit of weather forecasting is ~2 weeks.



Source: K. Cantner, AGI

Climate Projection. Drive by assumptions

- Long-term statistical average of weather (~30 years).
- Dependent on long-term assumptions about the chemical composition of the atmosphere (double CO_2), not real-time observations.
- Ensembles of climate models are effective at reproducing past climate.

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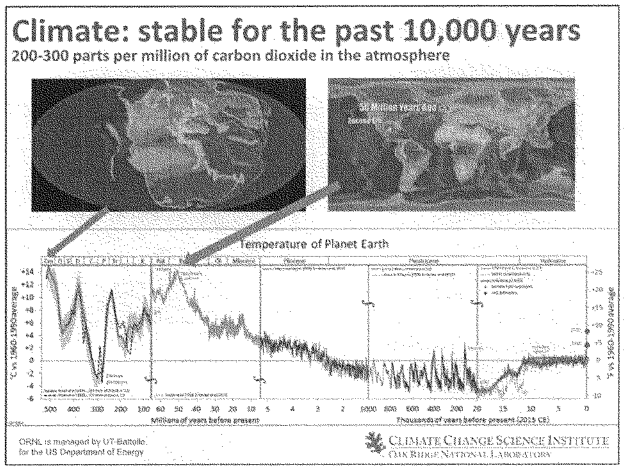
Climate: stable for the past 10,000 years
200-300 parts per million of carbon dioxide in the atmosphere
50 Million Years Ago
Temperature of Planet Earth
Millions of years before present
Thousands of years before present (2015 CE)
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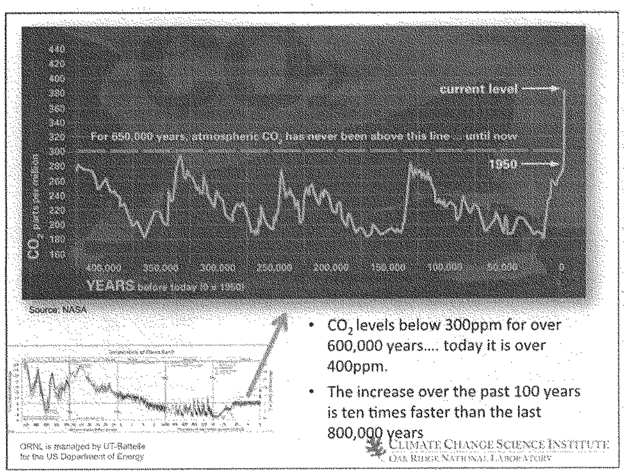
current level
For 650,000 years, atmospheric CO_2 has never been above this line ... until now
1950
CO_2 parts per million
400,000 350,000 300,000 250,000 200,000 150,000 100,000 50,000 0
YEARS before today (0 = 1950)
Source: NASA
• CO_2 levels below 300ppm for over 600,000 years.... today it is over 400ppm.
• The increase over the past 100 years is ten times faster than the last 800,000 years
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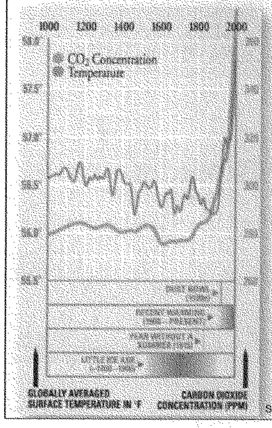
Carbon Dioxide and Temperature



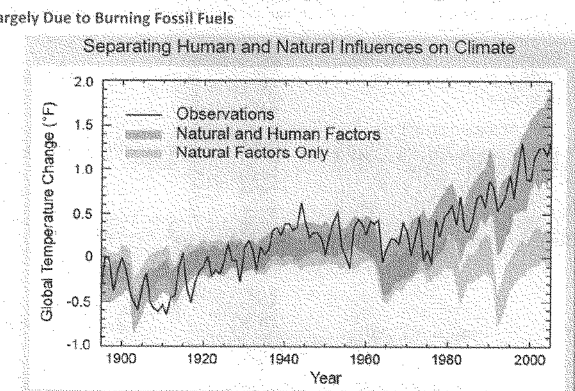
- CO_2 and temperature are closely related
- Current emission rates will result in ~1,000 ppm CO_2 levels by 2100
- It is not clear how the Earth will respond to these CO_2 levels. This is an extreme and risky experiment!

Source: Marian Koshland Science Museum

CLIMATE CHANGE SCIENCE INSTITUTE

Earth Temp: Rose 1.5°F Degrees in 100 Years

Largely Due to Burning Fossil Fuels



Source: Adapted from Huber and Knutti 2012

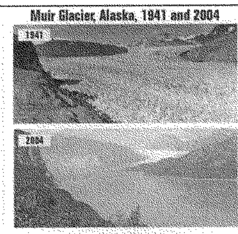
Do We See This Warming?

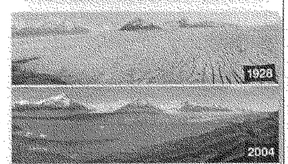
Current warming is consistent with indicators:

- Increasing ocean and atmosphere temperatures
- melting glaciers
- sea-level rise
- ocean acidity
- seasonal changes
- animal migrations, etc.

By 2100, warming could be 6-9°F (3-5°C)...resulting in new weather-related extremes (drought, floods, hurricanes, tornadoes, etc.)

Muir Glacier, Alaska, 1941 and 2004

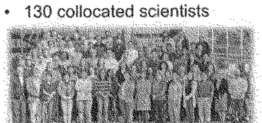


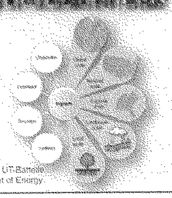


Climate Change Science Institute

Advancing the Knowledge of Climate Change and Understanding its Consequences

- Formed in 2009 to integrate ORNL's climate research programs
- 130 collocated scientists





Earth System Modeling

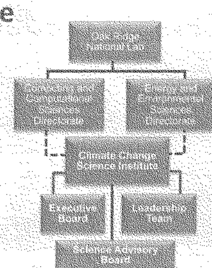
Integrative Ecosystem Science

Data Integration, Dissemination and Informatics

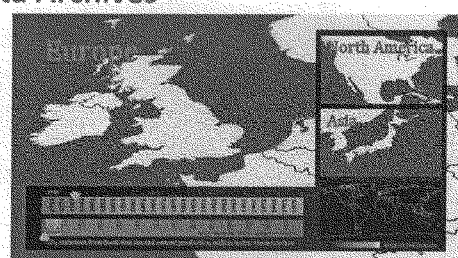
Impacts, Adaptation, and Vulnerability Science

CCSI Governance and Advice

Scientific Advisory Board
- Sasha Reed, U.S. Geological Survey, Chair
- Anthony Janetos, Boston University
- Jeff Arnold, Corp of Engineers
- Brian O'Neill, National Center for Atmospheric Research
- Anna Michalak, Stanford University
- David Hollinger, Forest Service
- Robert Chen, Columbia University
- Mike Frame, U.S. Geological Survey
- Curt Tilmes, NASA
  Christiane Jablonowski, University of Michigan
- Wayne Higgins, NOAA
- Jean-Francois Lamarque, National Center for Atmospheric Research



Data Archives

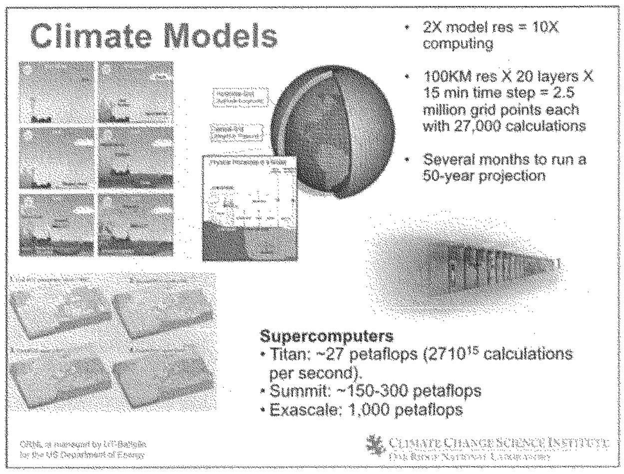


CO2 emissions from 1700-2006 in Europe and US.

Curates more than 10,000 environmental and climate data sets and many tools for their management, navigation, and analysis

- Carbon Dioxide
- Historic Weather
- Atmospheric Radiation
- Extreme Events
- NASA Biogeochem DACC
- Terrestrial Data Info System

7/20/17


Climate Models
• 2X model res = 10X computing
• 100KM res X 20 layers X 15 min time step = 2.5 million grid points each with 27,000 calculations
• Several months to run a 50-year projection
Supercomputers
• Titan: ~27 petaflops (27$10^{15}$ calculations per second).
• Summit: ~150-300 petaflops
• Exascale: 1,000 petaflops
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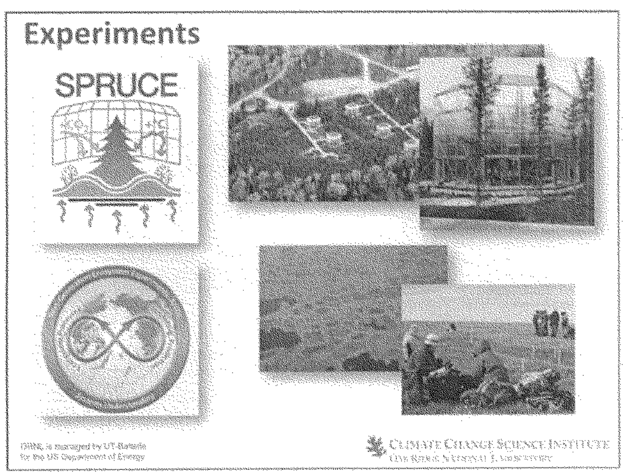
Experiments
SPRUCE
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CCSI Strategic Plan
Collaboration and Partnerships
SPRUCE
NGEE-Arctic
Climate Change Science Institute
Brookhaven National Laboratory
Sandia National Laboratories
Los Alamos National Laboratory
Nebraska Lincoln
University of New Hampshire
UTEP The University of Texas at El Paso
UAF University of Alaska Fairbanks
New Mexico Tech
Berkeley Lab
Lawrence Livermore National Laboratory
Florida State
Harvard University
OSU Oregon State
Lund University
Toronto
Duke
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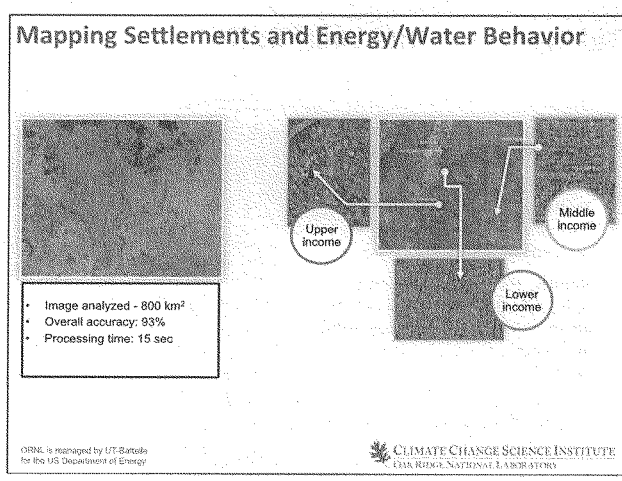
Mapping Settlements and Energy/Water Behavior
Image analyzed - 800 km²
Overall accuracy: 93%
Processing time: 15 sec
Upper income
Middle income
Lower income
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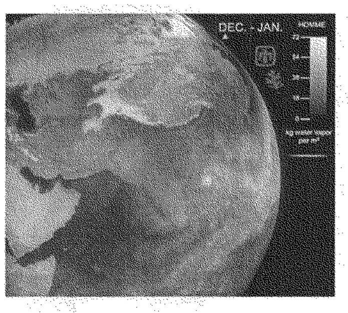
Integrating Models, Data, Experiments, People, and Computation



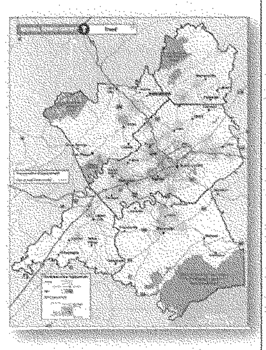
CCSI Role: advancing science and developing tools and information to understand how extremes can impact human and natural land-energy-water systems

- Impacts
- Vulnerability
- Resiliency
- Adaptation and mitigation options
- Better science through user engagement

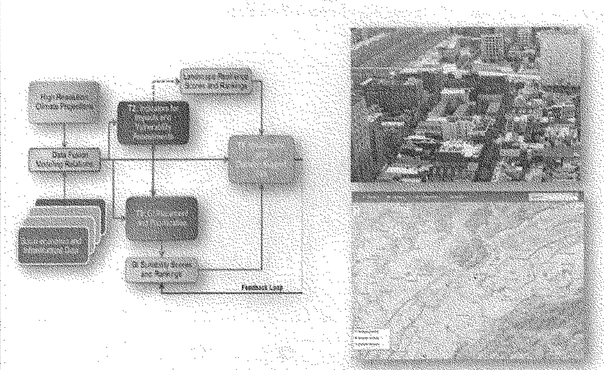
Taking This to the Local Scale

A different Knoxville climate and extreme weather events could impact:

- **Transportation.** How we move people and things around (ice, rain, snow, winds, fog, etc.).
- **Health.** How we stay healthy (e.g., safe temp range; access to affordable and safe energy, food, and water; adequate health care, etc.).



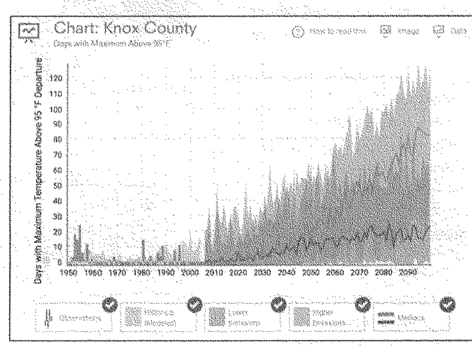
Urban-Climate Adaptation Tool: Optimizing Green Infrastructure to Reduce Runoff



Days With Maximum Temp Above 95°F

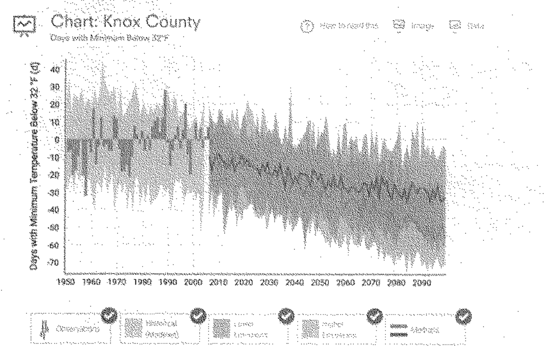
By 2100: Worst Case: ~80 more days (mean) Best Case: ~20 more days (mean)

Source: NOAA Climate Explorer (20 models)



Days With Minimum Temp Below 32°F

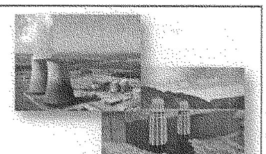
By 2100: Worst Case: ~55 fewer days (mean) Best Case: ~30 fewer days (mean)
Source: NOAA Climate Explorer (20 models)



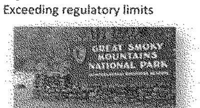
Climate Change Impacts
Positive and Negative

<u>**Warmer and Wetter Summer and Winter**</u>

- Heat-related health and infrastructure impacts
- Increased extreme weather events (floods, ice, tornadoes, etc.).
- Reduced labor productivity
- Increased (summer) and deceased (winter) energy use and utility costs
- Increased allergens and pollutants (including ozone)
- More frequent days above air quality regulatory levels that could restrict business development
- Increased and new pest populations
- Unwanted spread of non-native species
- Reduced agricultural productivity



Tipping Points:
- Additional infrastructure investment
- Out of network energy purchases
- Higher rates
- Exceeding regulatory limits



Economic Impacts: GSMNP generates over $1B and ~70,000 jobs. It is already experiencing climate-related changes:
- Change in season timing
- Plant and insect migrations
- Heat extremes
- Warmer winters

MacArthur Project

MacArthur Challenge: $100M to make measurable progress toward solving a significant societal problem

100& CHANGE

Resilient Cities

Ending Global Energy and Water Poverty

Partners (Team of 200):
- UT-K (ORNL)
- 100 Resilient Cities
- Skidmore, Owings, and Merrill
- Willis Re

Video

- Energy and water are critical to city services
- Billions of people remain trapped in poverty due to the lack of basic services
- Eliminate this poverty by optimizing the use of energy and water (net zero cities)
- We were 9th out of 2,000 – they picked the top eight.

Climate Change Science Institute

YouTube Link:
https://www.youtube.com/watch?v=Re-8YUOrFzY

YouTube Search: Climate Change Science Institute

Information Resources

Skeptical Science Website

http://www.skepticalscience.com

Compiles what climate skeptics say about the climate versus the current scientific findings.

Merchants of Doubt Film

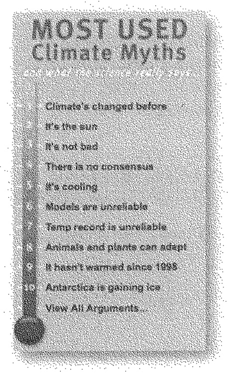
http://sonyclassics.com/merchantsofdoubt/

Chronicles the fossil fuel industries' campaign to undermine climate science (former tobacco and asbestos lobbyists)

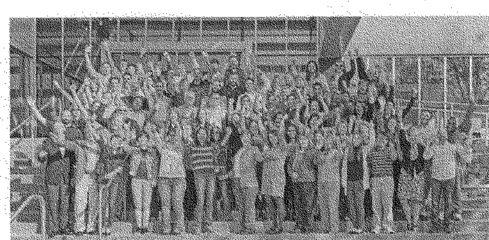
Carbon Nation Film

http://www.carbonnationmovie.com

Conservative and liberal entrepreneurs lowering their carbon footprint while creating economic wealth and jobs



Questions



CCSI Team

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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 5 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 CO_2 is a bureaucrat's dream. If you control climate, you control life.

So, back in 1995 was my first year here in the U.S. 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. OK. 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 CO_2 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 8 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 8-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. OK. 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 No. 1 obstacle was cost; No. 2, legislation; and I believe No. 4, 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. OK, 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 CO_2 from the air. Climeworks is a company in Switzerland. They are extracting CO_2 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. OK.

Mr. BOHLEN. So it is a very leading edge technology. The Climeworks executives feel that they can make money at $200 a ton CO_2 , 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 CO_2 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 CO_2 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 CO_2 , 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 1 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 toward alternatives. Could you talk about that in terms of how the free market is actually moving utility executive decisions toward 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 derisk 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. OK, 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 toward 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 toward 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 2-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 CO_2 in our air, find opportunity.

Thank you for helping us find it.

Senator CAPITO. Senator Markey, second round, 5 minutes.

Senator MARKEY. OK. 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 toward 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 2 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.]

[Additional material submitted for the record follows.]

WRITTEN STATEMENT

BY GREGORY B. JACZKO, CHAIRMAN

UNITED STATES NUCLEAR REGULATORY COMMISSION

TO THE

ENVIRONMENT AND PUBLIC WORKS COMMITTEE

AND THE

CLEAN AIR AND NUCLEAR SAFETY SUBCOMMITTEE

UNITED STATES SENATE

August 2, 2011

Chairman Boxer, Ranking Member Inhofe, Chairman Carper, Ranking Member Barrasso, and Members of the Committee, we appreciate the opportunity to appear before you to provide a summary of the findings of the NRC's Near-Term Task Force review of the Fukushima Dai-ichi nuclear accident.

I first want to thank, on behalf of the Commission, Dr. Charles Miller and the other members of the Task Force for all of their work in conducting the 90-day review. I also want to acknowledge the numerous other NRC staff who were available to the Task Force as a resource in conducting its review, as well as the Federal Emergency Management Agency, which engaged the Task Force in discussions of offsite emergency preparedness and provided insights on the U.S. National Response Framework, the Institute of Nuclear Power Operations – which shared information on the industry's post-Fukushima actions, and other groups and individuals who shared their views with the Task Force.

In my testimony today, I would like to provide you with a summary of the Task Force findings and recommendations. My colleagues and I are in the process of developing the Commission's direction to the NRC staff on addressing the Task Force recommendations.

Overview

The Near-Term Task Force was established in response to unanimous Commission direction to conduct a systematic and methodical review of NRC processes and regulations to determine whether the agency should make additional improvements to its regulatory system. The six-member Task Force, who collectively have over 135 years of regulatory experience, was responsible for making recommendations to the Commission for its policy direction in light of the accident at the Fukushima Dai-ichi Nuclear Power Plant. With its 90-day review completed, the Task Force issued its report to the Commission on July 12, 2011. The Commission made the report publicly available on July 13, 2011. The Task Force briefed the Commission on its findings on July 19, 2011.

Overall, the Task Force found that continued operation and continued licensing activities do not pose an imminent risk to public health and safety. The Task Force concluded that a sequence of events like the Fukushima Dai-ichi accident is unlikely to occur in the United States, and that some appropriate mitigation measures have been implemented, reducing the likelihood of core damage and radiological releases. The Task Force was clear, however, that any accident involving core damage and uncontrolled radioactive releases of the magnitude of Fukushima Dai-ichi—even one without significant health consequences—is inherently unacceptable.

The Task Force also concluded that a more balanced application of the Commission's defense-in-depth philosophy using risk insights would provide an enhanced regulatory framework. Such a framework would support appropriate requirements for increased capability to address events of low likelihood and high consequence, such as prolonged station blackout resulting from severe natural phenomena. This concept is the basis for the Task Force's proposal to redefine the level of protection regarded as adequate and provides the foundation for the Task Force's recommendations.

The Task Force report included a comprehensive set of twelve overarching recommendations. The Task Force recommendations are intended to clarify and strengthen the regulatory framework for nuclear power plants, and are structured around the focus areas of the NRC's defense-in-depth philosophy as applied to protection from natural phenomena; mitigation of prolonged station blackout events; and emergency preparedness. The Task Force also provided recommendations to improve the effectiveness of the NRC's programs.

In addition to these overarching recommendations, the Task Force report also includes a number of detailed recommendations that provide an integrated implementation strategy. The detailed recommendations are grouped into five categories: 1) a policy statement; 2) rulemakings; 3) orders; 4) staff actions; and 5) long-term evaluation topics. The longer-term evaluation topics are those issues about which sufficient information was not yet available for the near-term Task Force to make specific recommendations, and these topics were therefore deferred for possible consideration as part of the longer-term review.

Recognizing that conducting a rulemaking and the subsequent implementation typically takes several years to accomplish, the Task Force recommended interim actions to be taken in the near-term. The recommended orders are intended to provide those interim safety enhancements for protection, mitigation, and preparedness while the rulemaking activities are conducted.

Regulatory Framework

The Task Force's first recommendation is for the Commission to establish a logical, systematic and coherent regulatory framework for adequate protection that appropriately balances defense-in-depth and risk considerations. In the Task Force's view, the NRC's existing regulatory framework does not apply defense-in-depth and risk insights consistently. For example, beyond design basis events and severe accident issues have sometimes been addressed with new requirements such as the station blackout rule and in other cases have been addressed by voluntary industry initiatives such as severe accident management guidelines (SAMGs) which were not included in NRC requirements. The Task Force concluded that the proposed regulatory framework would serve all stakeholders well to facilitate staff and Commission decision-making, provide transparency and clarity for public stakeholders, and provide stability and predictability for the industry's business decisions on meeting regulatory requirements.

Protection Recommendations

With regard to protection of equipment from natural phenomena, the Task Force concluded that protection of important plant equipment from the appropriate external hazards is a key foundation of safety and that it is essential for nuclear plants to be protected against the appropriate design basis external events.

Design basis external hazards were established during the construction permit phase for operating U.S. plants, and they are not typically revisited through the life of the plant. The last construction permit for an operating U.S. plant was issued in 1978, and for many plants, this was completed in the 1960s. Since that time, there have been significant advancements in the state of knowledge and state of analysis methods for seismic and flooding hazards.

Through the years, various NRC programs have been initiated to evaluate the risk from external hazards, and actions were taken to address plant vulnerabilities that were identified. However, the hazards were not comprehensively reevaluated for all sites and the design basis was not necessarily updated. The Task Force concluded that the state of knowledge of seismic and flooding hazards has evolved to the point that it is appropriate for licensees to reevaluate the designs of existing nuclear power reactors to ensure that structures, systems and components important to safety will withstand such events without loss of capability to perform their intended safety function.

On this basis, the Task Force made its second recommendation, which is for the Commission to require licensees to reevaluate the design basis seismic and flooding hazards and as necessary, upgrade the protection of plant structures, systems and components. In its third recommendation, the Task Force also recommended, as part of the longer-term review, that the NRC evaluate potential enhancements to the capability to prevent or mitigate seismically- induced fires and floods.

The Task Force recognized that the proposed analysis and potential modifications would take time to implement. Therefore, as an interim action, the Task Force recommended seismic and flooding protection walkdowns be completed over the next several months to identify and address plant-specific vulnerabilities and verify the adequacy of monitoring and maintenance for protection features such as watertight barriers and seals.

Mitigation Recommendations

The Task Force also provided recommendations covering several aspects of mitigation of low frequency events. These include mitigation of prolonged station blackout events, containment overpressure prevention, hydrogen control, spent fuel pool cooling, and onsite emergency response capabilities.

Station Blackout

In order to strengthen the ability of nuclear power plants to deal with the effects of prolonged station blackout events, the Task Force made its fourth recommendation: the development of a comprehensive integrated approach to provide uninterrupted core and spent fuel cooling, and provide integrity of the reactor coolant system and containment. The proposed approach is divided into three phases: (1) an eight hour minimum coping phase; (2) a 72-hour extended coping phase; (3) and an offsite support phase. As an interim measure, the Task Force recommended that licensees be ordered to take reasonable action to protect existing mitigation equipment and to ensure that adequate capability is available to mitigate multiunit accidents.

Containment Overpressure

All boiling water reactors with Mark I containments voluntarily installed hardened wetwell vents in the early 1990's. The wetwell vents are intended to ensure containment integrity is maintained by preventing containment overpressure. The Task Force recommended that Mark I wetwell vents be a requirement and that the wetwell vent designs be enhanced to provide capability to open and to reclose as needed during prolonged station blackout scenarios. Eight boiling water reactor units in the United States have Mark II containment designs. Three of these units have installed hardened vents, and the remaining five units at Columbia, Limerick and Susquehanna have not installed hardened vents. The Task Force concluded that a Mark II under similar circumstances as Fukushima Dai-ichi units 1, 2 and 3, would have suffered similar consequences. Therefore, in its fifth recommendation, the Task Force recommended that reliable hardened wetwell vents be required at all boiling water reactors with Mark II containments. Additionally, the Task Force also recommended that the NRC staff reevaluate other containment designs as part of the long-term review to ensure that hardened vents are not necessary to mitigate beyond design basis accidents at other facilities.

Hydrogen Control

With regard to hydrogen control, the Task Force recommendation regarding enhanced mitigation of prolonged station blackout would, if implemented, reduce the likelihood of core damage and hydrogen production. This recommendation also includes provisions for backup power for hydrogen igniters in containment designs that require those features. In addition, while primarily aimed at containment overpressure prevention, enhanced wetwell vents for Mark I and Mark II containments designs would provide a reliable means for venting hydrogen to the atmosphere. These steps would greatly reduce the likelihood of hydrogen explosions from a severe accident.

Sufficient information from the detailed sequence of events and cause of hydrogen explosions at the Fukushima Dai-ichi plants was not available, however, for the Task Force to reasonably formulate any further specific recommendations related to combustible gas control. Therefore, in its sixth recommendation, the Task Force recommended that the NRC staff identify insights about hydrogen control and mitigation in primary containment and other buildings as part of the longer-term review.

Spent Fuel Safety

In the area of spent fuel pool safety, the Task Force concluded that the two most important insights from the Fukushima Dai-ichi accident relate to instrumentation to provide information about the condition of the pool and the spent fuel and the plant's capability for spent fuel cooling. To address both of these insights, the Task Force made its seventh recommendation to enhance spent fuel pool makeup capability and instrumentation for the spent fuel pool. Specifically, the Task Force recommended that spent fuel pool instrumentation be required to provide reliable information on the conditions in the spent fuel pool. Additionally, the Task Force recommended a requirement for spent fuel makeup to have safety-related backup power, and lastly, the Task Force recommended a requirement for a seismically qualified flow path to spray water into the spent fuel pools.

Onsite Emergency Response

The Task Force's eighth and final recommendation for enhanced mitigation capability is in the area of onsite emergency response. The Task Force recommended that the onsite emergency response capabilities be strengthened and integrated for a seamless response to severe accidents.

Emergency Response Recommendations

In addition to protection and mitigation measures, the Task Force examined how the insights from the accident at Fukushima Dai-ichi might inform both onsite and offsite emergency planning in the U.S. While the Task Force believes that the emergency planning basis in the U.S. provides radiological protection to members of the public, the Task Force identified two aspects of the Fukushima Dai-ichi accident that it concluded warrant additional consideration in the U.S. These two aspects are emergency planning for prolonged station blackout events and emergency planning for multiple unit events. In its ninth recommendation, the Task Force recommended that licensees be required to address prolonged station blackout and multiunit events in their facility's emergency plans. Examples of the proposed requirements include backup power supplies for communications equipment, and ensuring adequate staffing is available to respond to an event affecting more than one unit on a multiunit site.

In its tenth and eleventh recommendations, the Task Force proposed several topics that it believes warrant further evaluation during the longer-term review. These topics include protective equipment for emergency responders, qualifications for emergency decisionmakers, off-site radiation monitoring capability, and training for decisionmakers and the public on radiation safety and the appropriate use of potassium iodide.

NRC Programs

Finally, the Task Force identified one recommendation to enhance NRC programs. The Task Force concluded that enhancements to the NRC inspection program would improve its focus on safety. Specifically, in its twelfth recommendation, the Task Force recommended that the NRC strengthen regulatory oversight of licensee safety performance by balancing the use of risk by providing additional emphasis on defense-in-depth requirements.

Conclusion

In summary, the Task Force identified a number of important recommendations that touch on a broad range of issues. These recommendations seek to clarify the NRC's regulatory framework, to enhance safety through interim actions, orders, and rulemakings, and lastly, to provide recommended topics for long-term evaluation.

With the Task Force report now in hand, the Commission is considering the recommendations and deliberating on the path forward. We have a shared interest in stakeholder participation, including questions and feedback received at the Task Force's public meeting on July 28th. I look forward to ongoing dialogue and exchange of ideas among my colleagues and me in the coming weeks.

Chairman Boxer, Ranking Member Inhofe, Chairman Carper, Ranking Member Barrasso, and Members of the Committee, this concludes my formal testimony today. On behalf of the Commission, thank you for the opportunity to appear before you. We look forward to continuing to work with you to advance the NRC's important safety mission. We would be pleased to respond to any questions you may have.

Questions from Senator Barbara Boxer

QUESTION 1. **Questions have been raised at two recent EPW hearings about the "emergency authority" provided to you as Chairman, and how you used it following the disaster in Japan. Can you describe the authority provided to you under NRC regulations, including the Reorganization plan of 1980, and whether your actions have been consistent with that authority?**

ANSWER:

My actions have been consistent with the Chairman's emergency authority. Prompted by lessons learned after the Three Mile Island accident in 1979, Reorganization Plan No. 1 or 1980 section 3 "transfer[s]" to the Chairman all authority the Commission would otherwise possess pertaining to a particular nuclear emergency involving NRC-licensed facilities and materials. This Reorganization Plan emergency authority has been interpreted as not limited solely to emergencies involving specific NRC-regulated facilities or materials, and the Commission's Internal Procedures reflect this broad interpretation.

While the function of "declaring" an emergency is described as being included in this Reorganization Plan transfer of authority to the Chairman, the Reorganization Plan nowhere requires that a declaration of emergency occur prior to the Chairman's exercise of emergency authority. This is because the transfer of authority has already occurred by operation of the Reorganization Plan, and is not reliant on a formal Chairman declaration. Nonetheless, after the Japan earthquake and tsunami of March 11, 2011, prompt and frequent notice was given to Commissioners as well as the agency in general that the NRC was in emergency response mode, and I frequently briefed my Commission colleagues on the actions we were taking to respond to the crisis. I have also provided my Commission colleagues a summary on NRC actions taken in response to the Japan emergency. The NRC General Counsel has advised me that my actions have been consistent with applicable law.

QUESTION 2. **I share your strong commitment to ensuring safety at our nation's nuclear power facilities. In a recent letter to you, I urged the Commission to act transparently and expeditiously on the Task Force's recommendations. It is important that we not leave necessary safety improvements on the shelf while we wait for further study. Can you elaborate on what progress has been made by the Commission since our hearing on August 2nd to develop a plan of action for considering the Task Force recommendations and obtain stakeholder input?**

ANSWER:

The NRC staff sought external stakeholder feedback in a public meeting on August 31, 2011, regarding the Near-Term Task Force (NTTF) recommendations that stakeholders consider to be most important and that the NRC should undertake in the near-term. These recommendations were identified in a notation vote paper (SECY-11-0124, "Recommended Actions to be taken Without Delay from the Near-Term Task Force Report") dated September 9, 2011. A Commission meeting was conducted on September 14, 2011, during which representatives from other Federal and state agencies, the nuclear industry, and interested non-governmental organizations provided their views on the NRC staff's proposed near-term actions. On October 18, 2011, the Commission directed the NRC staff to proceed with action on these recommendations. The NRC staff is currently developing plans and schedules to implement the Commission's direction.

To further inform the prioritization of the balance of the NTTF recommendations, the NRC staff conducted a public meeting with representatives of the nuclear industry on September 21, 2011, in order to better understand their current plans and actions to address the lessons learned from the Fukushima Dai-ichi event. The NRC staff's proposed prioritization of all of the NTTF recommendations was submitted in a notation vote paper (SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned") on October 3, 2011. A Commission meeting was conducted on October 11, 2011, during which representatives from other Federal and state agencies, the nuclear industry, and interested non-governmental organizations provided their views on the NRC staff's proposed prioritization. SECY-11-0137 is currently under review by the Commission.

<u>QUESTION 3.</u> **The Task Force said a "patchwork of regulatory requirements" developed "piece-by-piece over the decades" should be replaced with a "logical, systematic and coherent regulatory framework" to bolster reactor safety. How do you reconcile these facts with the Task Force's statement that "continued operation and continued licensing activities do not pose an imminent risk to public health and safety?"**

ANSWER:

It is important to note that the Near-Term Task Force's (NTTF's) work reinforces the NRC's confidence in the continued safe operation of, and emergency planning for, U.S. nuclear power plants. The NTTF found that operating nuclear power plants are protected against low likelihood severe natural phenomena and have accident mitigation capabilities such that continued operation poses no imminent risk to public health and safety.

The phrase "patchwork of regulatory requirements" was not meant to imply that a gap in the regulations was identified. Rather, the NTTF found that, over the years, the NRC has addressed beyond-design-basis events on a case-by-case basis, with some elements being addressed by voluntary industry initiatives and others by specific regulations, thereby creating a "patchwork" regulatory framework. To ensure a consistent regulatory approach for these types of events, the NTTF recommended that the Commission establish a policy for balanced layers of defense against severe accidents, including protection, mitigation, and emergency preparedness, and, where appropriate, enhance the Commission's regulatory requirements within the new framework.

<u>QUESTION 4.</u> **I understand that the Natural Resources Defense Council has filed 18 petitions for Commission rulemakings or orders based on recommendations from the NRC Task Force. I also understand that NRC staff ordinarily responds on the sufficiency of such petitions for rulemaking or orders within 30 days of receiving the petitions. Do you think NRC staff has sufficient information to docket the petitions and move forward with rulemakings and orders? If not, how will the Commission proceed?**

<u>ANSWER:</u>

The NRC has received twelve petitions for enforcement action (under Title 10 of the *Code of Federal Regulations* (10 CFR) Section 2.206) and six petitions for rulemaking (under 10 CFR 2.802) from the Natural Resources Defense Council (NRDC), related to the NRC Near-Term Task Force (NTTF) recommendations. NRDC recently submitted a seventh petition for rulemaking addressing combustible gases. Because the different types of petitions are governed by different processes, separate responses are provided below for the two different types of petitions.

Petitions for Enforcement Action Filed Under 10 CFR 2.206: The NRC is processing the twelve petitions from NRDC (the petitioner) as a single action requesting that the NRC order licensees to take actions corresponding to recommendations by the NTTF to enhance plant safety after Fukushima. The NRDC cites the NTTF Report as the sole rationale and basis for the requests; no new information was provided. Under NRC Management Directive 8.11, "Review Process for 10 CFR 2.206 Petitions," the petitioner is offered the opportunity for a public meeting to address the NRC's Petition Review Board (PRB) prior to the PRB making an initial recommendation regarding acceptance of the petition. Having scheduled a public meeting with the petitioner for September 7th, NRDC asked to reschedule the meeting because of a desire to review the NRC staff recommendations to the Commission on the NTTF Report (see SECY-11-0124, "Recommended Actions to be taken Without Delay from the Near-Term Task Force Report," and SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned") prior to meeting with the PRB. Since, per Management Directive 8.11, the PRB would normally meet with a petitioner within two weeks of receipt of the petition, the NRC staff informed the petitioner that unless NRDC would like to have the public meeting by the end of October, the PRB would meet in November to decide on an initial recommendation, but would engage with the petitioner prior to developing its final recommendation. The petitioner's latest response, by email on October 26, 2011, stated that NRDC would like to meet with the PRB in December. The petitioner further stated that the Commission has taken up most of the issues in this petition and those issues are currently before the NRC staff. Hence, the PRB intends to meet in November to decide on an initial recommendation and meet with the petitioner in mid-December per NRDC's request before preparing its final recommendation regarding acceptance of the petition.

Petitions for Rulemaking Filed Under 10 CFR 2.802: The NRC has accepted, docketed, and noticed in the *Federal Register* the first six NRDC petitions for rulemaking (PRMs) related to the NTTF recommendations. These PRMs request the NRC to undertake the specific rulemaking activities recommended by the NTTF and cite the NTTF report as the sole rationale and basis for the rulemaking requests; no new information was provided. Because the Commission has already directed the NRC staff to proceed with rulemaking regarding station blackout events, the NRC is proceeding to evaluate the NRDC petition (PRM-50-101) that is associated with the station blackout rule. The other five PRMs will be held in abeyance until the Commission has given direction to the NRC staff on how to proceed with the NTTF topics associated with each of the PRMs.

The seventh NRDC PRM related to the Fukushima events was submitted on October 14, 2011, and requests that the NRC add requirements for the control of combustible gases (hydrogen) during accidents (NTTF Recommendation 6). The NRC is in the process of determining the sufficiency of this petition for docketing. The NRC will strive to issue the Notice of Receipt for this PRM within the 30-day goal stated in 10 CFR 2.802.

<u>QUESTION 5.</u> **The NRC took decisive actions after the tragedy of [September 11, 2001], ordering U.S. nuclear power plants to take a series of improved security measures. The NRC later codified those orders in regulations, with compliance required by March 31, 2010. In what ways is the process recommended by the Task Force parallel to what was used after 9/11? What assurance do we have that it will not take the Commission nearly a decade to implement the Task Force's recommendations to improve the safety of nuclear power reactors in the United States?**

<u>ANSWER:</u>

After the attacks of September 11, 2001, the Commission established new security requirements on the basis of adequate protection. These new requirements were not the result of immediate or imminent threats to NRC-licensed facilities, but rather resulted from new insights regarding potential security events. Similarly, after Japan's recent earthquake and tsunami and the resulting accident at the Fukushima Dai-ichi nuclear power plant, the Commission established a senior level task force known as the Near-Term Task Force (NTTF) to conduct both a short- and long-term analysis of potential lessons learned. The report produced by the NTTF identified twelve major recommendations with the potential to improve the safety of U.S. nuclear facilities.

The NRC is taking action on the Task Force recommendations. In the Staff Requirements Memorandum (SRM) dated October 18, 2011, "Recommended Actions to be taken Without Delay from the Near Term Task Force Report," the Commission directed the NRC staff to begin action without delay on those Near-Term Task Force recommendations with the greatest potential for safety improvement in the near term. In that SRM, the Commission directed that the NRC should strive to complete and implement the lessons learned from the Fukushima accident within 5 years – by 2016. In addition, the Commission directed that the staff should designate the station blackout (SBO) rulemaking as a high-priority rulemaking with a goal of completion within 24 to 30 months of the October 18, 2011 SRM.

The NRC staff developed a framework to methodically and systematically review the NTTF recommendations. The NRC staff's proposed prioritization of the NTTF recommendations was submitted in a notation vote paper (SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned") on October 3, 2011. The NRC staff has proposed to implement the recommendations, as appropriate, in accordance with established regulatory vehicles (i.e., Orders or Rulemaking). SECY-11-0137 is currently under review by the Commission.

In addition, the NRC staff also continues to evaluate approaches to implement all of the other recommendations that have resulted from the Fukushima Dai-ichi accident.

QUESTION 6. **It is my understanding that none of the spent fuel in dry cask storage at Fukushima was damaged or released radiation. If a facility transfers its spent fuel from pools to dry cask storage, wouldn't the consequences of an accident be lessened due to the reduced amount of fuel in its pool? If so, why doesn't the NRC reduce this risk in communities across the Nation by compelling spent fuel to be transferred to dry casks?**

ANSWER:

The NRC believes spent fuel pools and dry casks both provide adequate protection of public health and safety. Regarding the event at Fukushima, the information the NRC has to date indicates there was no significant offsite radioactive release from spent fuel stored in either the spent fuel pools or the dry casks. Although the NRC had some early concern with loss of water from the pools during the event, it now appears that the pools may have maintained an adequate inventory of water during the event, and the addition of water to the pools has maintained cooling of the stored fuel. We have not learned anything so far in our review of the Fukushima event that would indicate there is a safety or security reason to mandate accelerated transfer of spent fuel from pool storage to casks.

Consistent with the NRC mission of ensuring the protection of public health and safety, the NRC is continuing research regarding the behavior of spent fuel pools following a loss of cooling water. This effort includes an ongoing study of the effect of removing older fuel from the pool in an expedited manner and placing it in dry storage. The NRC recognizes that there are numerous details to consider when moving spent fuel to dry cask storage and plans to explore issues to ensure the safety of spent fuel storage.

QUESTION 7. **The Task Force concluded that a sequence of events like what occurred in Japan is unlikely to occur in the United States. Yet, the Task Force still recommended numerous safety improvements for nuclear power facilities around the country. In your view, what is the primary lesson learned from the accident in Japan thus far?**

ANSWER:

The primary lesson learned from the accident in Japan is a reinforcement of the importance of defense in depth in providing protection for public health and safety. This lesson has three important aspects. The first aspect is that each of the three fundamental defense in depth strategies (protection, mitigation, and emergency planning) is essential. The second aspect is that each strategy needs to be robust in itself and complementary to the other strategies, but independent from other strategies to the extent possible. The third aspect is that each strategy needs to seek out in a timely manner new information (e.g., updated seismic hazards information) that is necessary to maintain its level of effectiveness.

QUESTION 8. **The Union of Concerned Scientists (UCS) issued a response to the NRC Task Force's report, in which it urged the NRC to modify current emergency planning requirements. UCS urged the NRC to require plants to develop such plans based on a scientific assessment of the populations at risk for each site, rather than artificially limiting plans to areas within the current 10-mile planning zone. Do you agree that the NRC should re-evaluate current requirements for emergency preparedness and evacuation plans in light of what happened in Japan.**

ANSWER:

The Near-Term Task Force provided several recommendations that are intended to clarify and strengthen the current emergency preparedness regulatory framework. These recommendations may lead to the identification of issues that will warrant further study and longer term actions. As such, the NRC will continue to evaluate all of its current regulatory requirements to ensure that adequate protection of the public's health and safety will be maintained. In addition, the NRC staff in SECY 11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned," identified re-evaluation of the basis of emergency planning zone sizes as an additional recommendation warranting further consideration and potential prioritization.

QUESTION 9. **California's two nuclear power plants are located in areas of high seismic activity and I am concerned about their ability to withstand earthquakes. The Task Force has recommended requiring nuclear plants to confirm their seismic flooding hazards every 10 years and to address any new and significant information with safety upgrades. Do you agree that nuclear power plants in the United States should periodically re-evaluate seismic and flooding hazards in light of what has occurred in Japan?**

ANSWER:

The NRC staff identified the ten-year confirmation of seismic and flooding hazards as an item for long-term evaluation in SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned." The NRC staff is in the process of developing additional information regarding an approach and schedule for addressing this issue. However, the NRC staff also recommended near-term regulatory activities to interact with stakeholders and develop information requests. Licensees will be requested to: (1) re-evaluate site-specific seismic and flooding hazards, (2) perform seismic and flood protection plant walk-downs, and (3) identify actions that have been taken or planned to address plant-specific issues associated with the updated hazards or identified during the plant walk-downs. Information received from these near-term actions will be used to further inform the Commission's position regarding the periodic re-evaluation of seismic and flooding hazards.

Questions from Senator Thomas R. Carper

Question 1. **Can you explain how the NRC uses a mix of voluntary and mandatory regulations to ensure safety? How does the NRC ensure voluntary regulations are being enacted?**

ANSWER:

The NRC does not rely on voluntary measures to ensure safety. The agency affords adequate protection (safety) through the use of mandatory measures such as regulations, Orders and license conditions.

Regulatory commitments and voluntary programs can be useful since often they can be implemented more quickly than NRC requirements and they typically afford the licensee more flexibility to address the given situation. A licensee's implementation of a voluntary program may stem from the NRC encouraging the licensee to take additional actions beyond what is necessary to ensure adequate protection, but which provide added margin with respect to the overall safety of the facility. Under this scenario, there can be significantly reduced controls, and NRC typically does not inspect the voluntary program as part of its normal reactor oversight program.

<u>QUESTION 2.</u> **I can see a role for voluntary regulations - they can be quickly implemented without waiting on the federal government. However, they are meaningless if they are never enacted or not sustained over time. I was disappointed to see that when the NRC did a review of the voluntary severe accident management guidelines - very few plants were implementing all of the guidelines. Some plants were implementing very few of the guidelines at all. Can the NRC enforce voluntary programs without codifying them into law? What are the advantages and disadvantages of codifying voluntary programs? Should there be a time period after which all voluntary programs should become regulatory statute?**

<u>ANSWER:</u>

NRC regulations address specific safety, technical, or operational issues. By statute, NRC is required to put in place those regulations needed to ensure adequate protection of public health and safety, and the environment. For safety, technical, or operational issues that do not rise to the level of adequate protection, the NRC may pursue regulations in those areas if they provide a substantial increase in the overall protection of public health and safety. Alternatively, for those issues that do not rise to the level of adequate protection, the nuclear industry could voluntary develop and adopt an initiative to address a particular issue. However, the NRC does not routinely inspect the implementation of the voluntary industry initiatives, and cannot enforce them.

A voluntary program could be advantageous in allowing the NRC to focus resources on those issues of the highest safety importance, while allowing issues of low safety or risk importance to be addressed through voluntary programs. The NRC would not expend resources on the development of regulations and oversight of the residual issues. The disadvantages of a voluntary program is that if the issue of concern has a nexus to safety and, NRC determined that the issue was not being sufficiently addressed, we would be delayed in our ability to take effective action.

The NRC would not codify a voluntary industry initiative. Rather, if needed, the NRC would put in place regulations that address the particular safety, technical, or operational issue of concern. There is no time period associated with putting in place regulations for an issue that is being addressed through a voluntary industry initiative. Rather, the decision to put in place regulations would be dependent upon the safety significance of the issue.

QUESTION 3. **What we do know about the Fukushima [event] is that the Japanese underestimated the risk of that great of a tsunami and earthquake for that facility. I want to be sure that we are not underestimating our risks here at home. Please list the last time the NRC evaluated the seismic and flooding hazards for each of the 104 nuclear power plants.**

ANSWER:

The NRC requires that safety-significant structures, systems, and components at U.S. nuclear power plants be designed to take into account even rare and extreme seismic and tsunami events. All 104 U.S. nuclear power plants are built to withstand external hazards, including earthquakes, flooding, and tsunamis, as appropriate. Each plant's capability to withstand external hazards relevant to its site is reviewed by the NRC during its initial licensing.

The NRC has also made substantial effort over time to ensure that vulnerabilities to both internal and external hazards are considered and mitigated in the current design and licensing basis of its regulated facilities. The NRC routinely inspects the licensee's policies and procedures associated with responding to seismic and flooding hazards; as well as inspecting the licensee's structures, systems, and components used to mitigate the hazards. The NRC has also conducted two reviews of its regulated facilities over the last 25 years to ensure that they have included both internal and external hazards in their current plant design and licensing basis. These reviews are as follows:

(1) In 1988, the NRC's Generic Letter No. 88-20, "Individual Plant Examination for Severe Accident Vulnerabilities," requested plant owners to perform a systematic evaluation of plant-specific vulnerabilities and report the results to the Commission.

(2) In the mid to late 1990s, the NRC staff reviewed the potential for ground motions beyond the design basis as part of the Individual Plant Examination of External Events. From this review, the NRC staff determined that seismic designs of operating nuclear plants in the U.S. have adequate safety margins for withstanding earthquakes.

In addition, the NRC was in the process of performing a generic review of seismic hazards for existing plants before the Fukushima event occurred. This effort, knows as Generic Issue-199, "Implications of Updated Probabilistic Seismic Estimates in Central and Eastern United States on Existing Plants," will be incorporated into the NRC effort to re-evaluate the seismic hazards at U.S. nuclear plants in light of the Fukushima event, as outlined in SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned."

Questions from Senator Benjamin Cardin

QUESTION 1. **If the Commission delays action on Task Force recommendations on the grounds that you do not have enough information yet about what happened at Fukushima to move forward, does that suggest that the NRC also does not have enough information to move forward with re-licensing existing reactors or licensing new reactors?**

ANSWER:

The NRC is not delaying action on Task Force recommendations. Rather, the Commission is prioritizing the Task Force recommendations based on their potential level of safety significance. In the Staff Requirements Memorandum (SRM) dated October 18, 2011, "Recommended Actions to be taken Without Delay From The Near-Term Task Force Report," the Commission directed the NRC staff to begin action without delay on those Near-Term Task Force recommendations with the greatest potential for safety improvement in the near-term.

The NRC continues to believe that its regulatory framework and requirements provide for a rigorous and comprehensive license review process that examines the full extent of design, siting, and operation of nuclear power plants. Therefore, the agency is continuing to process existing applications for new reactors and license renewal applications in accordance with the schedules that have been established. The NRC has the necessary regulatory tools to require changes to existing licenses or certified designs should the agency determine that such changes are necessary.

Questions from Senator James M. Inhofe

QUESTION 1. **Commissioner Apostolakis cited in his opening statement that "there is growing evidence that the historical record of tsunamis had not been used properly to determine the design basis of Fukushima Daiichi and consequently the protection of the plant was not sufficient." He added that "it was not unthinkable or unforeseen."**

- **Please explain how an accident triggered by a design basis improperly calculated in a different regulatory system provides a basis for concluding that our existing regulatory framework is no longer acceptable, especially without having analyzed the comparative differences in regulatory requirements.**

- **Please describe any evidence from the Fukushima event that indicates our regulations would not have been adequate.**

ANSWER:

The NRC places an emphasis on learning from operating experience, both foreign and domestic, in order to ensure that the operation of U.S. nuclear facilities does not pose an unacceptable risk to public health and safety. The event at Fukushima Dai-ichi is a prime example of operating experience from which both the NRC and the U.S. nuclear industry can potentially learn a great deal. Although the outcome of the event may have been influenced by the approach taken in Japan to determining the facility's design basis tsunami and/or by the particular characteristics of the Japanese regulatory system, it reinforces the importance of ensuring that U.S. nuclear facilities are adequately protected from similar extreme external events. As with any piece of operating experience, the NRC proposes to learn as much as possible from the event at Fukushima and apply that knowledge to further the NRC's safety mission here in the U.S.

<u>QUESTION 2.</u> **You have repeatedly stated that U.S. plants are safe and the task force says there is no imminent risk, yet you continuously refer to the "urgency of these safety issues" and the need to proceed "expeditiously." What specific evidence from the Fukushima accident supports your sense of urgency?**

<u>ANSWER:</u>

The NRC has been very closely monitoring the activities in Japan and reviewing all available information associated with the events at the Fukushima Dai-ichi nuclear power plant. The NRC's urgency to proceed with a subset of NTTF recommendations is based upon its consideration of the relative safety benefit to be derived from each recommendation as it would contribute to maintaining the NRC's defense-in-depth philosophy. The NRC's urgency to begin the process of stakeholder interaction on this subset of NTTF recommendations is related to its desire to provide ample opportunity for all NRC stakeholders to inform the NRC of their views regarding these important topics and to assist the NRC in formulating the correct course of action for U.S. nuclear facilities.

<u>QUESTION 3.</u> **Your colleagues voted on this matter on July 19, July 27, and July 29. You did not vote until August 9. Please indicate how many times you requested an extension of voting time, the length of those extensions, and why you were unable to vote in a timely manner considering the importance of the matter and your stated desire to move forward expeditiously.**

<u>ANSWER</u>:

This question refers to SECY-11-0093, "Near Term Report and Recommendations for Agency Actions following the Events in Japan," dated July 12, 2011. I filed my initial, timely comments on August 9th, which was during the period of a single Commission-endorsed 5-day extension to vote that followed all of the Commission's established processes. Rather than focusing my vote on process issues, my seven-page vote offered my policy views on each of the twelve nuclear safety recommendations made by the Commission's task force. Leading up to my vote, I proposed a detailed plan for collegial Commission review of the task force report that included Commission meetings with stakeholders, a federal register notice seeking public comment, and additional staff input.

<u>**QUESTION 4.**</u> **In your speech at the Press Club, you stated: "As Chairman, I'm committed to ensuring that the Commission has all the information it needs to make timely decisions and take decisive actions in response to the task force recommendations." Yet you directed the Executive Director for Operations (EDO) to withdraw his recommendations to the Commission on how to proceed with the task force recommendations. Do you believe your direction to the EDO is consistent with your Press Club statement?**

<u>ANSWER:</u>

My actions were consistent with my statutory responsibilities and are in the best interests of nuclear safety.

QUESTION 5. **Do you believe it is appropriate in your role as Chairman to screen materials before agency staff provides them to the Commission?**

ANSWER:

As Chairman, I am responsible for the day-to-day administration of the agency, managing the staff, executing Commission decisions, keeping the Commission informed on matters within the Commission's functions, and for developing policy planning and guidance for consideration by the Commission.

<u>QUESTION 6:</u> **The Commission provides direction to the EDO to carry out staff actions. Do you believe it is within your authority as the agency's principal executive officer to interpret the Commission's direction?**

<u>ANSWER:</u>

As a general matter, yes, that is within my direction. Under Reorganization Plan No. 1 of 1980 § 2(b), the Chairman is specifically responsible "for assuring that the Executive Director for Operations and the staff of the Commission. . . are responsible to the requirements of the Commission in the performance of its functions." Thus, the Chairman is ultimately responsible and accountable for the EDO's response to Commission direction and any necessary interpretation of such direction. In addition, § 4(b) of the Reorganization Plan states that "[t]he Executive Director for Operations shall report for all matters to the Chairman," thereby further confirming the Chairman's supervisory role vis-à-vis the EDO. The Commission does, however, have the ability to clarify any direction it has given to agency staff if it believes that implementation is not consistent with the Commission's intent. Additionally, under the Commission's Internal Procedures, the Chairman shares draft tasking memoranda with the Commission before issuing the memoranda to agency staff, which further promotes consistency between Commission direction and staff response.

QUESTION 7. **Is the Japanese nuclear safety regulator independent, as the NRC is in the U.S.?**

ANSWER:

Currently, Japan has a nuclear regulatory structure that involves multiple organizations collaborating with an overarching "double check" by a Diet-appointed Commission. The Nuclear and Industrial Safety Agency (NISA) is responsible for approximately 85% of the regulatory program; NISA is a subdivision of Japan's Ministry of Economy, Trade and Industry, an organization with a broad portfolio that includes both regulatory and promotional aspects of nuclear energy. The Japanese Government is preparing to separate the regulatory portion from the promotional portion, by assigning the new regulatory body to Japan's Ministry of the Environment. This reorganization is scheduled to take place in April 2012.

<u>QUESTION 8.</u> **Does the Japanese nuclear safety regulator calculate tsunami risk the same way the NRC does?**

ANSWER:

We believe the Japanese regulator and the NRC determine tsunami risk differently. Our current understanding is that the Japanese regulator uses a deterministic method to verify the design tsunami by using criteria based on historical records.

The NRC uses a hierarchical three step approach to determine tsunami risk at U.S. nuclear facilities. The first two steps eliminate regions and plants having no tsunami risk. The third step assesses risk at facilities where the elevation of safety significant structures, systems and components cannot be conclusively shown to exceed the calculated tsunami run-up. The assessment is based on numerical modeling of elements including source modeling, wave propagation and shoreline inundation. Tsunami heights determined by modeling must exceed all known historical tsunami heights.

Regardless of approach used, it is important to make correct assumptions and to use all available information, including information on uncertainty.

<u>QUESTION 9.</u> **Do Japanese nuclear plants provide a similar level of protection for their emergency generators and fuel tanks as US plants do?**

<u>ANSWER:</u>

In Japan and the U.S., all safety equipment, including emergency diesel generators and fuel tanks, is designed and maintained to specifications that ensure, with a margin of safety, that the equipment will work when needed. Correctly anticipating conditions that may occur during an event is critical to ensuring the emergency equipment is sufficiently designed and protected.

Based on the lessons learned from Fukushima, the United States, Japan, and other countries are taking steps to ensure that design assumptions at all nuclear plants are sufficient to ensure the protection of emergency equipment.

QUESTION 10. **Is the licensing process for Japanese reactor operators administered by an independent regulator with a comparable level of rigor to the NRC's process?**

ANSWER:

NRC requirements for reactor operator licensing are found in 10 CFR Part 55. In Japan, the Nuclear and Industrial Safety Agency (NISA) administers the licensing of reactor operators. NISA has responsibility over licensees for safety examination, licensing, inspection, and hearings on incidents and events. NISA exists as a part of the Ministry of Economy, Trade and Industry (METI). METI, through the Agency for Natural Resources and Energy (ANRE), also promotes nuclear power. The Japanese Government is preparing to separate the regulatory portion from the promotional portion, by assigning the new regulatory body to Japan's Ministry of the Environment, this reorganization is scheduled to take place in April 2012. Japan's Nuclear Safety Commission (NSC) provides oversight of NISA's licensing and inspection activities.

Beyond this structure, the NRC does not currently have sufficient information to make a more detailed comparison.

QUESTION 11. **Are Japanese reactor operators authorized to take any and all actions necessary to protect public health and safety the way we do, without seeking corporate or political input?**

ANSWER:

The licensed operators of United States nuclear facilities are authorized and expected to take any and all actions necessary to protect public health and safety without seeking corporate or political input. In addition, U.S. regulations provide that a licensee may take reasonable action that departs from a license condition or a technical specification in an emergency, when this action is immediately needed to protect public health and safety and no action consistent with license conditions and technical specifications that can provide adequate or equivalent protection is immediately apparent. NRC does not have information on the requirements for reactor operators in Japan.

The NRC, other U.S. government agencies, and the U.S. nuclear industry remain actively involved in the process of developing an understanding of the precise sequence of events which occurred at Fukushima Dai-ichi in the wake of the March 11, 2011 tsunami.

Environment and Public Works Committee Hearing
August 2, 2011
Follow-Up Questions for Written Submission

Questions for Commissioner Apostolakis

Questions from Senator Barbara Boxer

1. The Task Force concluded that a sequence of events like what occurred in Japan is unlikely to occur in the United States. Yet, the Task Force still recommended numerous safety improvements for nuclear power facilities around the country. In your view, what is the primary lesson learned from the accident in Japan thus far?

> Answer: In my view, the primary lesson learned from the accident in Japan is that we should reevaluate the correctness of the design basis for major natural events on a periodic basis.

2. The Union of Concerned Scientists (UCS) issued a response to the NRC Task Force's report, in which it urged the NRC to modify current emergency planning requirements. UCS urged the NRC to require plants to develop such plans based on a scientific assessment of the populations at risk for each site, rather than artificially limiting plans to areas within the current 10-mile planning zone. Do you agree that the NRC should reevaluate current requirements for emergency preparedness and evacuation plans in light of what happened in Japan?

> Answer: Yes. We should reevaluate current requirements for the emergency planning zone (EPZ) using site-specific Level 3 probabilistic risk assessments (PRAs) which, in addition to considering the populations at risk, also take into account potential accident sequences, local geography, and other relevant factors. A Level 3 PRA that is updated periodically would allow for a better informed evaluation of emergency planning using current site-specific conditions.

3. California's two nuclear power plants are located in areas of high seismic activity and I am concerned about their ability to withstand earthquakes. The Task Force has recommended requiring nuclear power plants to confirm their seismic and flooding hazards every 10 years and to address any new and significant information with safety upgrades. Do you agree that nuclear power plants in the United States should periodically re-evaluate seismic and flooding hazards in light of what occurred in Japan?

> Answer: Yes. I agree with the Task Force that seismic and flooding hazards should be reevaluated at appropriate intervals throughout the life of the nuclear power plant.

Questions from Senator Thomas R. Carper

1. Can you explain how the NRC uses a mix of voluntary and mandatory regulations to ensure safety? How does the NRC ensure voluntary regulations are being enacted?

> Answer: The NRCs regulations provide requirements that are necessary for a finding of reasonable assurance of adequate protection to public health and safety and common defense and security. The NRC does not rely on industry voluntary initiatives to ensure adequate protection. Voluntary initiatives can, however, enhance safety in areas which go beyond the NRC's regulatory requirements. The NRC sometimes looks at voluntary initiatives during our inspections. However, the NRC does not routinely ensure that voluntary initiatives are implemented appropriately.

2. I can see a role for voluntary regulations -they can be quickly implemented without waiting on the federal government. However, they are meaningless if they are never enacted or not sustained over time. I was disappointed to see that when the NRC did a review of the voluntary severe accident management guidelines -very few plants were implementing all of the guidelines. Some plants were implementing very few of the guidelines at all. Can the NRC enforce voluntary programs without codifying them into law? What are the advantages and disadvantages of codifying voluntary programs? Should there be a time period after which all voluntary programs should become regulatory statute?

> Answer: Shortly after the accident at Fukushima Daiichi, the NRC issued inspection guidance to look at severe accident mitigation guidelines (SAMGs) at operating plants. These guidelines were put in place in the 1990s and were voluntary industry initiatives. The NRC reviewed the adequacy of these SAMGs and how they've been maintained over the years. Inspections confirmed that every site has SAMGs, but revealed inconsistent implementation, inconsistencies in procedure availability and control, and some issues with training and use of SAMGs in emergency response exercises.
>
> NRC's assurance of adequate protection does not rely on voluntary industry initiatives. The NRC does not enforce compliance with voluntary programs because they are not required for adequate protection. However, some voluntary initiatives could be codified if the NRC determined, based on new information, that they are necessary for adequate protection or they increase safety substantially and are cost justified. The Fukushima accident is certainly prompting the NRC to reconsider the voluntary nature of some industry initiatives.

3. What we do know about the Fukushima is that the Japanese underestimated the risk of that great of a tsunami and earthquake for that facility. I want to be sure we are not underestimating our risks here at home. Please list the last time the NRC evaluated the seismic and flooding hazards for each of the 104 nuclear power plants.

> Answer: The NRC evaluated the seismic and flooding hazards for each site during the initial licensing review for each reactor at the site. In the mid to late 1990's, the NRC requested that each licensee identify and report all plant-specific vulnerabilities to severe accidents caused by seismic events; internal fires; and high winds, floods, and other external initiating events. All licensees reviewed the potential for earthquake ground motions beyond the design basis. As a result of this review, several plants made plant modifications to improve protection against these external events.
>
> The NRC is currently in the process of conducting a generic review (i.e., Generic

Issue-199 (GI-199), Implications of Updated Probabilistic Seismic Hazard Estimates in the Central and Eastern U.S. on Existing Plants), to re-assess the resistance of U.S. nuclear plants to earthquakes. This is an ongoing effort and a draft Generic Letter has been developed to move the process into the regulatory assessment stage. The Generic Letter was available for public comment until October 31, 2011. The NRC staff will consider the comments before finalizing the Generic Letter, which the staff expects to issue near the end of this year. The approach outlined in the Generic Letter would have U.S. nuclear power plants perform their analysis within either one or two years, depending on the analysis method used, and deliver their results to the NRC. The agency will then determine whether additional actions are necessary.

In addition, the Commission is considering whether and how to implement seismic and flood hazard reevaluation recommendations resulting from the Near-Term Task Force review of insights from the Fukushima Daiichi accident.

Questions from Senator James M. Inhofe

1. You cited in your opening statement that "there is growing evidence that the historical record of tsunamis had not been used properly to determine the design basis of Fukushima Daiichi and consequently the protection of the plant was not sufficient." You also mentioned that the accident "was not unthinkable or unforeseen." Please describe in more detail the information that informed your conclusion.

> Answer: My judgment is based on discussions with technical experts, both within and outside of the U.S., and reports written about the event. This includes the government of Japan's report to the International Atomic Energy Agency, in which it states that "the assumption on the frequency and scale of tsunamis was insufficient." One tsunami expert told me that there were 10 earthquakes in the last 10 years worldwide of magnitude 8.4 or less on the Richter scale which had generated tsunamis higher than 10 meters. It does not appear that this information was taken into account. Furthermore, the design basis did not include data on a major tsunami that occurred more than 1000 years earlier. In a New York Times article (March 26, 2011), a tsunami expert referred to Japan's underestimation of the tsunami risk as "a cascade of stupid errors".
>
> In addition, critical equipment at Fukushima Daiichi was located in low elevations of the plant. A risk assessment for flooding would have revealed these vulnerabilities. In light of the above, I concluded that the accident was not unthinkable or unforeseen.

2. The Chairman has repeatedly commented that failure to implement the task force recommendations may delay new plant applications. Do you agree with that assessment?

> Answer: The Commission has already decided to implement several of the Task Force recommendations. At this point, I do not see the necessity for delay. New reactor license applications are judged against current regulatory requirements. These licenses could be issued, if approved by the Commission, without the need for any new license conditions associated with the Fukushima Near-Term Task Force recommendations. If the Commission approves issuance of these licenses, it can use existing regulatory approaches to implement those approved recommendations applicable to new reactor licensees just as it will for operating reactor licensees. This approach provides adequate mechanisms to address regulatory changes that the Commission determines are necessary. However, the Commission is currently deliberating on aspects of the Task Force recommendations as well as the issuance of the first new reactor licenses.

3. How will you, as a commissioner, work to ensure that the agency does not slip into a malaise and that regulatory decisions and actions, whether connected to issues stemming from Fukushima or not, take longer and longer to resolve?

> Answer: As an individual Commissioner, I will continue to do my part and work with my colleagues to ensure that timely decisions are made. If there is a potential delay associated with an agency decision, I will scrutinize the cause of the delay and only support it when there are compelling reasons for it.

Questions for Commissioner Magwood
August 2, 2011
Follow-up Questions for Written Submission

Senator Barbara Boxer

1. **The Task Force concluded that a sequence of events like what occurred in Japan is unlikely to occur in the United States. Yet, the Task Force still recommended numerous safety improvements for nuclear power facilities around the country. In your view, what is the primary lesson learned from the accident in Japan thus far?**

   In my view, the primary lesson we must learn from the accident in Japan is that we must be prepared to deal with the unexpected. We must assure that if an unlikely or unforeseen event occurs that challenges the safety of a nuclear plant, we have appropriate mitigating measures in place that will allow plant operators to recover from the initiating event and prevent damage to the core and releases that could threaten the environment and the public. For example, we need to be prepared for the loss of on-site and off-site electric power. We also need to review preparedness at multi-unit sites. I believe a central aspect of our regulatory response to Fukushima will be to assure that licensees have the equipment, procedures, and training to recover from the unexpected.

2. **The Union of Concerned Scientists (UCS) issued a response to the NRC Task Force's report, in which it urged the NRC to modify current emergency planning requirements. UCS urged the NRC to require plants to develop such plans based on a scientific assessment of the populations at risk for each site, rather than artificially limiting plans to areas within the current 10-mile planning zone. Do you agree that the NRC should re-evaluate current requirements for emergency preparedness and evacuation plans in light of what happened in Japan?**

   I believe the ten-mile emergency planning zone is still an appropriate basis for emergency preparedness. Fukushima demonstrated the significant amount of time which authorities have to take appropriate protective measures when responding to an emergency situation occurring at a U.S.-style light water reactor. Still, it is appropriate to examine all lessons from the Fukushima event. The NRC staff has recommended a longer-term effort to review current emergency planning requirements, including the 10 mile emergency planning zone, and I support this initiative.

3. **California's two nuclear power plants are located in areas of high seismic activity and I am concerned about their ability to withstand earthquakes. The Task Force has recommended requiring nuclear power plants to confirm their seismic and flooding hazards every 10 years and to address any new and significant information with safety upgrades. Do you agree that nuclear power plants in the United States should periodically re-evaluate seismic and flooding hazards in light of what occurred in Japan?**

I recently visited California's nuclear power plants and learned a great deal about the operation of Diablo Canyon Power Plant and the San Onofre Nuclear Generating Station (SONGS) and the external hazards against which we must protect.

As a part of its effort to complete an application to renew the operating license for Diablo Canyon, Pacific Gas and Electric (PG&E) has conducted a complete safety evaluation report. The NRC has made clear that it will not finalize a decision on this license renewal application until the company completes 3-D seismic studies forced on the nearby Shoreline Fault which was discovered in 2008. PG&E must also obtain a coastal consistency certification before its application can be approved. Similarly, Southern California Edison (SCE) has proposed a multimillion dollar study that would use a new technology including 3-D reflecting mapping offshore that would be used to detect hidden earthquake faults to better assess seismic conditions near SONGS.

I believe these efforts are appropriate measures to address uncertainties associated with the seismic risks facing these facilities. This work responds to new information and applies new technology. In these specific cases and as a general matter, I believe it would place the public at greater risk to wait ten years to respond to new information regarding seismic, flooding or any other external hazard. The Commission currently has before it staff's recommendation to have licensees reevaluate the seismic and flooding hazards at their sites against current NRC requirements and guidance, and if necessary, update the design basis and structures, systems and components important to safety and to protect against the updated hazards. The Commission has approved a staff recommendation to interact with stakeholders and develop information requests under 10 CFR 50.54(f). As a result, we will ask all nuclear plant licensees to reevaluate site-specific seismic and flooding hazards, perform seismic and flood protection walk-downs and identify actions that have been taken or are planned to address plant specific issues associated with the hazards or identified during the plant walk downs.

I believe that this approach is the best way to assure licensees understand the seismic and flooding risks faced by their plants and respond appropriately to address them—without waiting for a decadal review.

Senator Thomas R. Carper

1. **Can you explain how the NRC uses a mix of voluntary and mandatory regulations to ensure safety? How does the NRC ensure voluntary regulations are being enacted?**

   It is my belief that if something is of safety significance, it is best to make it part of our regulatory requirements. However, there are some areas of interest which involve safety risks of relatively low significance. NRC's ability under existing law to regulate areas that do not impact human health is very limited. In such cases, voluntary efforts may be appropriate and may be implemented more quickly.

   Industry's Groundwater Protection Initiative is a prime example of a voluntary initiative that advances the protection of public health and addresses public concerns. The NRC has fostered an environment which encourages industry to take actions of this nature and continually monitors and periodically assesses the effectiveness of these initiatives. If the agency finds that voluntary efforts are not being conducted in a committed fashion, this information will be presented to the Commission, and the Commission can consider other measures.

2. **I can see a role for voluntary regulations – they can be quickly implemented without waiting on the federal government. However, they are meaningless if they are never enacted or not sustained over time. I was disappointed to see that when the NRC did a review of the voluntary severe accident management guidelines very few plants were implementing all of the guidelines. Some plants were implementing very few of the guidelines at all. Can the NRC enforce voluntary programs without codifying them into law? What are the advantages and disadvantages of codifying voluntary programs? Should there be a time period after which all voluntary programs should become regulatory statute?**

   I believe the ongoing evaluation of performance of voluntary initiatives is preferable to a broadly applied time limit. The NRC assesses all voluntary initiatives and if they are found to not have widespread implementation or that the voluntary efforts are not being conducted in an effective fashion, then the issue can be revisited. If the Commission finds that regulatory action is needed, it can make a voluntary initiative a mandatory requirement through the issuance of an order; initiation of a rulemaking; or by incorporating the program into the licensee's operating license as a license condition.

   The matter of severe accidents management guidelines (SAMGs) is an important example. The accidents at Fukushima demonstrated the importance of having plant operators who are well prepared and well supported by technically sound and practical procedures and guidelines. It is clear that a planned approach to command and control during decision making during an emergency is vital. SAMGs are an important aspect to emergency response capability. Following the Fukushima accident the NRC issued Temporary Instruction 2515/183 to its resident inspectors to ensure licensee compliance with existing requirements related to SAMGs and extensive damage mitigation guidelines and to collect information on the readiness of these measures for use under various external challenges. As you noted in your question, our inspectors observed inconsistent implementation of SAMGs and attributed it to the voluntary nature of this initiative.

As a result, the Commission is currently considering a staff recommendation to require licensees to strengthen and integrate emergency operating procedures, severe accident management guidelines, and extensive damage mitigation guidelines. Our evaluation of this effort is now underway and I anticipate this work will result in a more aggressive NRC stance with regard to these procedures.

3. **What we do know about the Fukushima is that the Japanese underestimated the risk of that great of a tsunami and earthquake for that facility. I want to be sure we are not underestimating our risks here at home. Please list the last time the NRC evaluated the seismic and flooding hazards for each of the 104 nuclear power plants.**

The NRC requires that safety-significant structures, systems, and components at U.S. nuclear power plants be designed to take into account even rare and extreme seismic and tsunami events. All 104 U.S. nuclear power plants are built to withstand external hazards, including earthquakes, flooding, and tsunamis, as appropriate. Each plant's capability to withstand external hazards relevant to its site is reviewed by the NRC during its initial licensing.

The NRC has also made substantial efforts over time to ensure the vulnerabilities from both internal and external hazards are considered and mitigated in the current design and licensing basis of its regulated facilities. The NRC routinely inspects each licensee's policies and procedures associated with responding to seismic and flooding hazards. Additionally NRC inspects the licensee's structures, systems, and components used to mitigate the hazards. The NRC has also conducted two reviews of its regulated facilities over the last 25 years to ensure that they have included both internal and external hazards in their current plant design and licensing basis. These reviews are as follows:

(1) In 1988, the NRC's Generic Letter No. 88-20, Individual Plant Examination for Severe Accident Vulnerabilities," requested plant owners to perform a systematic evaluation of plant-specific vulnerabilities and report the results to the Commission.

(2) In the mid to late 1990s, the NRC staff reviewed the potential for ground motions beyond the design basis as part of the Individual Plant Examination of External Events. From this review, the staff determined that seismic designs of operating nuclear plants in the U.S. have adequate safety margins for withstanding earthquakes.

The NRC was preparing to perform a generic review of seismic hazards for existing plants before the Fukushima event occurred. This effort, knows as Generic Issue-199, "Implications of Updated Probabilistic Seismic Estimates in Central and Eastern United States on Existing Plants," will be incorporated into the NRC effort to re-evaluate the seismic hazards at U.S. nuclear plants in light of the Fukushima event, as outlined in SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned."

Through these substantial efforts, the NRC has ensured that the risk associated with seismic and flooding hazards is not underestimated at nuclear power plants in the U.S. The NRC remains convinced that U.S. nuclear power plants are designed and operated in a manner that protects public health and safety.

Senator James M. Inhofe

1. **You have mentioned that the task force didn't consider some issues in its report and cite the use of potassium iodide as one example. What other issues did the task force overlook that you believe would benefit from a more methodical review?**

   While the Task Force was staffed with highly-experienced experts, it was a very small group that, by necessity, was allowed a very short period of time in which to complete its work. The report the Task Force produced is insightful and impressive, but I do believe there are areas not covered by the report that require further considerations. As you note, I believe that NRC should review our approach to the use of potassium iodide (KI) in the aftermath of a multi-unit accident. I am hopeful that we will obtain actionable information from Japan regarding that nation's experience with KI distribution in the days after Fukushima.

   I also believe that Fukushima demonstrated the vital importance of ensuring access to ultimate heat sinks. Ultimate heat sinks are sources of water necessary to operate, shut down, and cool down a nuclear plant safely following an accident. Water for ultimate heat sinks is frequently supplied directly from large-surface water bodies, such as rivers, lakes, or oceans. If those sources of water were to become unavailable as a function of an external event such as an earthquake or tsunami, any efforts to mitigate the consequences of an accident would be hobbled.

2. **The Chairman has repeatedly commented that failure to implement the task force recommendations may delay new plant applications. Do you agree with that assessment?**

   No, I do not. First, I believe that the Commission has taken and is taking appropriate action regarding the Task Force recommendations and other suggestions that have emerged from staff's engagement with our many stakeholders. I note that the Task Force concluded in its report that all current early site permits already meet the requirements of Task Force Recommendation 2.1, relating to the design-basis seismic and flooding analysis and that all of the current new plant and design certification applicants are addressing all necessary requirements.

   Most important, the NRC staff has emphasized on many occasions that any new requirements the Commission may adopt in the aftermath of Fukushima will be applied to all licensees operating nuclear plants in the United States—despite whether these plants operate now or come on line in the future. Given this, I see nothing to be gained in delaying action on new plant applications.

3. **How will you, as a commissioner, work to ensure that the agency does not slip into a malaise and that regulatory decisions and actions, whether connected to issues stemming from Fukushima or not, take longer and longer to resolve?**

   You raise an important concern that is inherent in the work of an agency with the complex array of activities such as is faced by the NRC. Fortunately, NRC has a strong cadre of experienced managers and a culture based on tracking work and assigning clear responsibility for its completion. Still, I see some evidence of the challenge you highlight even now, particularly as we, like other agencies, must make careful choices as to the allocation of resources and personnel. In a budget-constrained environment, it is simply a reality that some work will be delayed as new activities—such as those responding to the lessons of Fukushima—are added.

   It is my view, which I have expressed to the staff and through my votes on relevant issues that our efforts associated with the regulatory responses to Fukushima must be integrated with the normal work of the agency and prioritized based on their safety significance. With this approach, all of our work can be planned, tracked, and implemented in the same manner that it has always been.

   In this manner, the Commission will be in a strong position to monitor the staff's work and, where necessary, make appropriate corrections. Much of this oversight will need to occur on a daily basis. However, I expect this will be most apparent in the annual budgeting process, which is where the Commission establishes agency priorities and determines funding for all activities.

ENCLOSURE

Environment and Public Works Committee Hearing
August 2, 2011
Follow-Up Questions for Written Submission

Questions for Commissioner Ostendorff
Senator Barbara Boxer

1. The Task Force concluded that a sequence of events like what occurred in Japan is unlikely to occur in the United States. Yet, the Task Force still recommended numerous safety improvements for nuclear power facilities around the country. In your view, what is the primary lesson learned from the accident in Japan thus far?

Answer

In my view, the primary lesson learned from the accident in Japan thus far is that nuclear power plants must have sufficient capability to cope with an extended loss of all alternating current power or what is referred to as a "station blackout." In my vote on the Near Term Task Force report (SECY-11-0093), I expressed support for the initiation of rulemaking to strengthen station blackout mitigation capability at nuclear power plants. Moreover, in my vote on the staff's recommended actions to be taken without delay (SECY-11-0124), I proposed to designate the station blackout rulemaking as a high-priority rulemaking to be completed within 24 months of the date of the associated Staff Requirements Memorandum (SRM) for SECY-11-0124. In the final SRM, the Commission directed the staff to designate the rulemaking as a high-priority with a goal of completion within 24 to 30 months of October 18, 2011.

In addition to dealing with an extended station blackout event, I also took away other important lessons learned. These lessons include the importance of reliable venting systems for certain boiling water reactor containments; the importance of severe accident management procedures; assessment of protection from external hazards such as seismic and flooding; the value of having reliable spent fuel pool instrumentation; and emergency preparedness for multi-unit events.

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Questions for Commissioner Ostendorff
Senator Barbara Boxer

2. The Union of Concerned Scientists (UCS) issued a response to the NRC Task Force's report, in which it urged the NRC to modify current emergency planning requirements. UCS urged the NRC to require plants to develop such plans based on a scientific assessment of the populations at risk for each site, rather than artificially limiting plans to areas within the current 10-mile planning zone. Do you agree that the NRC should reevaluate current requirements for emergency preparedness and evacuation plans in light of what happened in Japan?

Answer

In SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned," the NRC staff identified emergency planning zone (EPZ) size as an additional issue with a nexus to the Fukushima accident that may warrant further regulatory action. While the NRC staff's assessment of this issue is incomplete, the staff has judged that this issue, among others, warrants further consideration and potential prioritization. A determination of whether any regulatory actions are necessary will be made after the staff completes further evaluation of the issue. As this further evaluation is conducted, I believe that the existing framework for a 10-mile EPZ along with the flexibility to expand the EPZ, if circumstances warrant, will continue to provide for the protection of the public during a nuclear accident.

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Questions for Commissioner Ostendorff
Senator Barbara Boxer

3. California's two nuclear power plants are located in areas of high seismic activity and I am concerned about their ability to withstand earthquakes. The Task Force has recommended requiring nuclear power plants to confirm their seismic and flooding hazards every 10 years and to address any new and significant information with safety upgrades. Do you agree that nuclear power plants in the United States should periodically re-evaluate seismic and flooding hazards in light of what occurred in Japan?

Answer

I agree that nuclear power plants in the United States should re-evaluate the safety implications of hazards, such as seismic and flooding, when new and significant information becomes available. In this regard, I voted to support the NRC staff's recommendation in SECY-11-0124, "Recommended Actions to be Taken Without Delay from the Near Term Task Force Report," to initiate regulatory activities aimed at conducting re-evaluations and walkdowns of site-specific seismic and flooding hazards. I believe that what we learn from these near-term regulatory activities will help inform whether the NRC should require a periodic re-evaluation, such as the 10-year confirmation of seismic and flooding hazards recommended by the Task Force.

As an aside, I had the opportunity with Commissioner Magwood to visit California's two nuclear power plants—San Onofre on October 25 and Diablo Canyon on October 26 (Dr. Horner from your staff joined us). During both plant visits, we had significant discussions on seismic hazards analysis.

ENCLOSURE

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August 2, 2011
Follow-Up Questions for Written Submission

Questions for Commissioner Ostendorff
Senator Thomas R. Carper

1. Can you explain how the NRC uses a mix of voluntary and mandatory regulations to ensure safety? How does the NRC ensure voluntary regulations are being enacted?

Answer

The NRC does not rely on voluntary measures to ensure safety; by statute, the NRC is required to put in place those regulations needed to ensure adequate protection of public health and safety. For safety, technical, or operational issues that do not rise to the level of adequate protection, the nuclear industry could voluntarily develop and adopt initiatives to address a particular issue.

Regulatory commitments and voluntary programs are useful since they can often be implemented more quickly than the development of formal NRC requirements. Furthermore, they typically enable more flexibility to address the given situation. The manner in which a regulatory commitment or voluntary program is treated by the licensee and by the NRC can vary, depending on the nature of the regulatory commitment or voluntary program and its relation to a regulatory requirement. For example, the NRC may use a licensee's regulatory commitments to help decide if further regulatory actions need to be taken. Under such circumstances, the NRC would typically perform an inspection to determine if the licensee is implementing the regulatory commitment, if the regulatory commitment is being managed through the licensee's commitment tracking system, and whether the regulatory commitment should be placed into a controlled document such as the final safety analysis report. The NRC staff currently performs periodic audits of licensee commitments at operating nuclear power plants on a triennial basis.

Alternatively, a licensee's implementation of a voluntary program may stem from the NRC encouraging the licensee to take additional actions that, while not necessary to ensure adequate protection, provide added margins with respect to the overall safety of the facility. Under this scenario, the NRC may choose to inspect the voluntary program as part of its reactor oversight program depending on the specific circumstance.

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Questions for Commissioner Ostendorff
Senator Thomas R. Carper

2. I can see a role for voluntary regulations - they can be quickly implemented without waiting on the federal government. However, they are meaningless if they are never enacted or not sustained over time. I was disappointed to see that when the NRC did a review of the voluntary severe accident management guidelines - very few plants were implementing all of the guidelines. Some plants were implementing very few of the guidelines at all. Can the NRC enforce voluntary programs without codifying them into law? What are the advantages and disadvantages of codifying voluntary programs? Should there be a time period after which all voluntary programs should become regulatory statute?

Answer

The NRC does not routinely inspect the implementation of voluntary industry initiatives, and cannot enforce them. Further, regulatory commitments made by licensees are generally not enforceable NRC requirements.

Voluntary programs can be advantageous in allowing the NRC to focus resources on those issues of the highest safety importance, while allowing issues of low safety or risk importance to be addressed through voluntary programs. The disadvantages of a voluntary programs is that if the issue of concern has a nexus to safety and the NRC determined that the issue was not being sufficiently addressed, we would be limited in our ability to take effective action because of the lack of enforceability.

If the NRC concludes that a regulatory requirement is needed to address a particular safety, technical, or operational issue of concern, then the NRC would take action in one of several ways including: 1) issuing an order, 2) initiating rulemaking, or 3) incorporating a licensee's commitment or voluntary program into its operating license as a license condition

There is no time period associated with putting in place regulations for an issue that is being addressed through a voluntary industry initiative. Rather, the decision to put in place regulations would be dependent upon the safety significance of the issue.

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Questions for Commissioner Ostendorff
Senator Thomas R. Carper

3. What we do know about the Fukushima is that the Japanese underestimated the risk of that great of a tsunami and earthquake for that facility. I want to be sure we are not underestimating our risks here at home. Please list the last time the NRC evaluated the seismic and flooding hazards for each of the 104 nuclear power plants.

Answer

The NRC takes steps to ensure that vulnerabilities to both internal and external hazards are considered and mitigated in the current design and licensing basis of its regulated facilities. For example, the NRC requires that safety-significant structures, systems, and components at U.S. nuclear power plants be designed for protection against natural phenomena, including seismic and tsunami events. All 104 U.S. nuclear power plants are built to withstand such external hazards, and each plant's capability to withstand external hazards relevant to its site characteristics is reviewed by the NRC during its initial licensing.

In addition, the NRC routinely inspects licensee procedures and systems, structures, and components associated with mitigating the consequences of internal and external hazards. The NRC has also conducted two reviews of its regulated facilities over the last 25 years to ensure that they have included both internal and external hazards in their current plant design and licensing basis. These reviews are as follows:

(1) In 1988, the NRC's Generic Letter No. 88-20, "Individual Plant Examination for Severe Accident Vulnerabilities," requested plant owners to perform a systematic evaluation of plant-specific vulnerabilities and report the results to the Commission.

(2) In the mid to late 1990s, the NRC staff reviewed the potential for ground motions beyond the design basis as part of the Individual Plant Examination of External Events. From this review, the staff determined that seismic designs of operating nuclear plants in the U.S. have adequate safety margins for withstanding earthquakes.

The NRC was preparing to perform a generic review of seismic hazards for existing plants before the Fukushima event occurred. This effort, knows as Generic Issue-199, "Implications of Updated Probabilistic Seismic Estimates in Central and Eastern United States on Existing Plants," will be considered in the NRC's effort to re-evaluate the seismic hazards at U.S. nuclear plants in light of the Fukushima event, as outlined in SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned."

Through these efforts, the NRC can help ensure that the risk associated with seismic and flooding hazards is not underestimated at nuclear power plants in the U.S.

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Follow-Up Questions for Written Submission

Questions for Commissioner Ostendorff
Senator James M. Inhofe

1. The Chairman has repeatedly commented that failure to implement the task force recommendations may delay new plant applications. Do you agree with that assessment?

Answer

No, I do not agree with that assessment.

In a September 9, 2011 Order (CLI-11-05), the Commission declined to suspend adjudicatory, licensing, and rulemaking activities in light of the recent events at the Fukushima Daiichi nuclear power plant. As stated in the Order, the Commission noted that "whether we adopt the Task Force recommendations or require more, or different, actions associated with certified designs or COL applications, we have the authority to ensure that certified designs and combined licenses include appropriate Commission-directed changes before operation."

We further noted that "we find no imminent risk to public health and safety if we allow our regulatory processes to continue. Instead of finding obstacles to fair and efficient decision-making, we see benefits from allowing our processes to continue so that issues unrelated to the Task Force's review can be resolved. We have well-established processes for imposing any new requirements necessary to protect public health and safety and the common defense and security. Moving forward with our decisions and proceedings will have no effect on the NRC's ability to implement necessary rule or policy changes that might come out of our review of the Fukushima Daiichi events."

As I described in my August 18, 2011 responses to your follow-up questions from the June 16, 2011 hearing, the Commission can apply lessons learned from Japan to new plant activities in a variety of different ways using existing regulatory processes.

ENCLOSURE

Environment and Public Works Committee Hearing
August 2, 2011
Follow-Up Questions for Written Submission

Questions for Commissioner Ostendorff
Senator James M. Inhofe

2. How will you, as a commissioner, work to ensure that the agency does not slip into a malaise and that regulatory decisions and actions, whether connected to issues stemming from Fukushima or not, take longer and longer to resolve?

Answer

I believe in applying the NRC's Principles of Good Regulation in carrying out my responsibilities as an NRC Commissioner. In my view, three principles—efficiency, clarity, and openness—are of particular importance to avoid the malaise you have expressed concern over. In my tenure, I believe that my decisions have been made without undue delay and have sought to promote efficiency, clarity, and openness in the NRC's regulatory activities. For example, I have supported expedited rulemaking where it has been appropriate for the circumstance. I also strive to ensure that there is clarity of direction from the Commission to the NRC staff, clarity of our regulations to those that must implement them, and clarity of our communications with our external stakeholders. Lastly, I have undertaken initiatives to enhance the NRC's engagement with external stakeholders to best inform our regulatory decisions.

ENCLOSURE

Environment and Public Works Committee Hearing
August 2, 2011
Follow-Up Questions for Written Submission

Questions for Commissioner Ostendorff
Senator James M. Inhofe

3. You commented in the hearing about the NRC's lack of understanding of whether or not the Fukushima operators actually used their hardened vents. At this time, do you believe the NRC knows enough about the Fukushima hardened vents to fix it right the first time?

Answer

I believe that while all of the details of what happened with the hardened vents during the Fukushima accident are not yet fully understood, we do know enough to recommend a requirement for reliable hardened vents. In particular, several reactor units at the Fukushima Daiichi site experienced containment pressure increases during the accident that substantially exceeded the design pressure. I agree with the NRC's Near Term Task Force's evaluation that having a reliable hardened vent system would significantly enhance the capability to mitigate serious beyond design basis accidents. As such, I have voted to support the development of regulatory requirements through orders for reliable hardened vents at certain boiling water reactor facilities.

Commissioner Kristine L. Svinicki's Responses to Questions for the Record
Environment and Public Works Committee Hearing
August 2, 2011

<u>Senator Barbara Boxer</u>

1. **The Task Force concluded that a sequence of events like what occurred in Japan is unlikely to occur in the United States. Yet, the Task Force still recommended numerous safety improvements for nuclear power facilities around the country. In your view, what is the primary lesson learned from the accident in Japan thus far?**

   In my view, the primary lesson learned from the accident in Japan is the need to ensure that we maintain a willingness to question and examine the bases of our regulatory action in light of any new information. We must also use this tragic event to advance the goals of nuclear safety – both domestically and within the international cooperative framework. Fukushima reminds us to challenge our current assumptions regarding fundamental preparedness to respond to the unlikely or unexpected.

2. **The Union of Concerned Scientists (UCS) issued a response to the NRC Task Force's report, in which it urged the NRC to modify current emergency planning requirements. UCS urged the NRC to require plants to develop such plans based on a scientific assessment of the populations at risk for each site, rather than artificially limiting plans to areas within the current 10-mile planning zone. Do you agree that the NRC should re-evaluate current requirements for emergency preparedness and evacuation plans in light of what happened in Japan?**

   The NRC's Near-Term Task Force provided several recommendations that are intended to clarify and strengthen the current emergency preparedness regulatory framework. These recommendations may lead to the identification of additional issues that will warrant further study and longer term actions. As such, the NRC will continue to evaluate all of its current regulatory requirements to ensure that adequate protection of public health and safety will be maintained. In my view, this evaluation should also assess the facts as we are able to gather them regarding the Japanese experience with evacuation and relocation of the affected population, as well as any differences between the Japanese and U.S. regulatory systems.

3. **California's two nuclear power plants are located in areas of high seismic activity and I am concerned about their ability to withstand earthquakes. The Task Force has recommended requiring nuclear plants to confirm their seismic flooding hazards every 10 years and to address any new and significant information with safety upgrades. Do you agree that nuclear power plants in the United States should periodically re-evaluate seismic and flooding hazards in light of what has occurred in Japan?**

   Yes. The NRC staff is in the process of developing additional information regarding an approach and schedule for addressing this issue. Licensees will be requested to: (1) re-evaluate site-specific seismic and flooding hazards, (2) perform seismic and flood protection plant walk-downs, and (3) identify actions that have been taken or planned to address plant-specific issues associated with the updated hazards or identified during the plant walk-downs. Information received from these near-term actions will be used to further inform potential regulatory actions going forward.

Enclosure

<u>Senator Thomas R. Carper</u>

1. **Can you explain how the NRC uses a mix of voluntary and mandatory regulations to ensure safety? How does the NRC ensure voluntary regulations are being enacted?**

   The NRC does not rely on voluntary measures to ensure adequate protection of public health and safety. The agency ensures adequate protection through the use of mandatory measures such as regulations, license conditions, and orders. These measures are supported by regulatory guides, standard review plans, and other similar tools.

   For issues that are above and beyond what is needed to provide reasonable assurance of public health and safety, voluntary initiatives can be an optimal vehicle to achieve desired outcomes. The manner in which a regulatory commitment or voluntary program is treated by the licensee and by the NRC staff can vary, depending on the nature of the regulatory commitment or voluntary program and its relation to a regulatory requirement. For example, the NRC may use a licensee's regulatory commitments to help decide if further regulatory actions need to be taken. Under such circumstances, the NRC would typically perform an inspection to determine if the licensee is implementing the regulatory commitment, if the regulatory commitment is being managed through the licensee's commitment tracking system, and whether the regulatory commitment should be placed into a controlled document such as the final safety analysis report. Alternatively, the licensee's implementation of a voluntary program may stem from the NRC encouraging the licensee to take additional actions that may not be necessary to ensure adequate protection, but which provide added margin with respect to the overall safety of the facility. Inspection of the implementation of voluntary industry initiatives is done on a case-by-case basis.

2. **I can see a role for voluntary regulations - they can be quickly implemented without waiting on the federal government. However, they are meaningless if they are never enacted or not sustained over time. I was disappointed to see that when the NRC did a review of the voluntary severe accident management guidelines - very few plants were implementing all of the guidelines. Some plants were implementing very few of the guidelines at all. Can the NRC enforce voluntary programs without codifying them into law? What are the advantages and disadvantages of codifying voluntary programs? Should there be a time period after which all voluntary programs should become regulatory statute?**

   By statute, NRC is required to put in place those regulations needed to ensure adequate protection of public health and safety. For safety, technical, or operational issues that do not rise to the level of adequate protection, the NRC may pursue regulations in those areas if they provide a substantial increase in the overall protection of public health and safety and are cost-justified. Alternatively, for those issues that do not rise to the level of adequate protection, the nuclear industry could voluntarily develop and adopt an initiative to address a particular issue. The NRC does not enforce voluntary industry programs because they are not regulatory requirements necessary to ensure adequate protection of public health and safety.

   Voluntary programs are advantageous when they allow the NRC to focus resources on those issues of the highest safety importance, while allowing issues of low safety or risk importance to be addressed voluntarily by licensees. There is no time period associated with putting in place regulations for an issue that is being addressed through a voluntary industry initiative.

What we do know about Fukushima is that the Japanese underestimated the risk of that great of a tsunami and earthquake for that facility. I want to be sure that we are not underestimating our risks here at home. Please list the last time the NRC evaluated the seismic and flooding hazards for each of the 104 nuclear power plants.

The NRC requires that safety-significant structures, systems, and components at U.S. nuclear power plants be designed to take into account even rare and extreme seismic and tsunami events. All 104 U.S. nuclear power plants are built to withstand external hazards, including earthquakes, flooding, and tsunamis, as appropriate. Each plant's capability to withstand external hazards relevant to its site is reviewed by the NRC during its initial licensing.

The NRC has also made substantial effort over time to ensure that vulnerabilities to both internal and external hazards are considered and mitigated in the current design and licensing basis of its regulated facilities. The NRC routinely inspects the licensee's policies and procedures associated with responding to seismic and flooding hazards; as well as inspecting the licensee's structures, systems, and components used to mitigate the hazards. The NRC has also conducted two reviews of its regulated facilities over the last 25 years to ensure that they have included both internal and external hazards in their current plant design and licensing basis. These reviews are as follows:

(1) In 1988, the NRC's Generic Letter No. 88-20, "Individual Plant Examination for Severe Accident Vulnerabilities," requested plant owners to perform a systematic evaluation of plant-specific vulnerabilities and report the results to the Commission.

(2) In the mid to late 1990s, the NRC staff reviewed the potential for ground motions beyond the design basis as part of the Individual Plant Examination of External Events. From this review, the NRC staff determined that seismic designs of operating nuclear plants in the U.S. have adequate safety margins for withstanding earthquakes.

In addition, the NRC was in the process of performing a generic review of seismic hazards for existing plants before the Fukushima event occurred. This effort, known as Generic Issue-199, "Implications of Updated Probabilistic Seismic Estimates in Central and Eastern United States on Existing Plants," will be incorporated into the NRC effort to re-evaluate the seismic hazards at U.S. nuclear plants in light of the Fukushima event, as outlined in SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned."

Through these substantial efforts, the NRC has ensured that the risk associated with seismic and flooding hazards is not underestimated at nuclear power plants in the U.S. The NRC remains convinced that U.S. nuclear power plants are designed and operated in a manner that protects public health and safety.

Senator James M. Inhofe

1. **Why do you think a more rigorous process is important to the objective of nuclear safety?**

   The NRC's Near-Term Task Force found that a sequence of events like the Fukushima Dai-ichi accident is unlikely to occur in the United States, and that continued operation and continued licensing activities do not pose an imminent risk to public health and safety. Therefore, we are in a position to take deliberate, yet expeditious, action commensurate with our level of understanding of the events in Japan. We expect that the set of facts regarding the sequence of events and accident progression at Fukushima Dai-ichi will continue to grow, and our level of understanding will continue to evolve over the next several years. A comprehensive set of facts regarding what transpired in Japan is crucial to ensuring that we correctly identify and diagnose issues that may require NRC action for continued assurance of adequate protection of public health and safety.

2. **You urge scrutiny of the task force proposal by the ACRS. How will their expert testimony serve the objective of ensuring public health and safety? Do you believe that Chairman Jaczko's March 23 tasking memorandum adequately harnessed their expertise?**

   Statutorily mandated by the Atomic Energy Act of 1954, as amended, the Advisory Committee on Reactor Safeguards (ACRS) reviews and reports on safety studies and reactor facility license and license renewal applications; advises the Commission on the hazards of proposed and existing production and utilization facilities and the adequacy of proposed safety standards; initiates reviews of specific generic matters or nuclear facility safety-related items; and provides advice in the areas of health physics and radiation protection. Throughout my tenure on the Commission, I have found that the ACRS provides valuable insights and advice to the Commission. The Committee's advice reflects the breadth and depth of the collective knowledge and experience of the Committee's members, as well as the diversity of their views. The Task Force's recommendations span a wide variety of complex issues with varying safety implications and potentially significant regulatory impacts. This calls for regular ACRS engagement on the longer term review. The March 23 tasking memorandum's direction to have the ACRS review the Near-Term Task Force report was an appropriate first step. The ACRS's continued engagement will be essential as the agency moves forward.

3. **The Chairman has repeatedly commented that failure to implement the task force recommendations may delay new plant applications. Do you agree with that assessment?**

   No, I do not. The NRC has the regulatory mechanisms to apply any new requirements the Commission may adopt in response to the lessons-learned arising from the events at Fukushima to licensees of both currently operating and future plants.

4. How will you, as a Commissioner, work to ensure that the agency does not slip into a malaise and that regulatory decisions and actions, whether connected to issues stemming from Fukushima or not, take longer and longer to resolve?

During my service as a Commissioner, I have found the NRC to be an organization of dedicated safety professionals who are mindful of the importance of their work to the Nation. Their dedication, coupled with disciplined adherence to NRC's Principles of Good Regulation by both the agency's staff and the Commission itself, will keep our efforts focused.

NUCLEAR ENERGY INSTITUTE

Marvin S. Fertel
PRESIDENT AND
CHIEF EXECUTIVE OFFICER

July 15, 2011

The Honorable Gregory B. Jaczko
Chairman
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Mail Stop 016 C1
Rockville, MD 20852

Subject: NRC Near-Term Task Force Report

Project Number: 689

Dear Chairman Jaczko:

The nuclear energy industry is reviewing the NRC Near-Term Task Force's Recommendations for Enhancing Reactor Safety in the 21st Century and we look forward to providing comments to the staff on the recommendations. In general, the industry agrees with many of the issues identified by the task force. While there are some near-term actions that are clear from the available information, the basis for many of the recommendations clearly was disadvantaged by the fact that detailed information from the accident was, as the task force noted, "unavailable, unreliable and ambiguous."

The task force report lacks the rigorous analysis of issues that traditionally accompanies regulatory requirements proposed by the NRC. Better information from Japan and more robust analysis is necessary to ensure the effectiveness of actions taken by the NRC and avoid unintended consequences at America's nuclear energy facilities. The report also discusses at length proposals to modify the existing regulatory framework for nuclear energy facilities. If the commission decides to pursue some or all of the task force proposals related to the regulatory framework, these activities should be separated from the specific Fukushima Daiichi lessons learned recommendations.

The nuclear energy industry has taken seriously the accident at Fukushima Daiichi and continues to compile lessons learned that can be applied at U.S. reactors. As the NRC task force has concluded throughout the 90-day review, U.S. nuclear energy facilities are safe. Since the March accident, the industry has conducted detailed inspections at our facilities and taken steps necessary to enhance safety as well as responded to NRC-mandated actions at the facilities. As the NRC confirmed, every

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company operating a nuclear plant has verified its ability to safely manage the facility even in an extreme event, regardless of its cause.
We will continue to work with the NRC to identify potential enhancements in safety that should be made. In this regard, the continued assessment of information from Japan and the sharing of information compiled by the NRC, the industry and others that are assessing the accident will be critical to reaching the correct lessons learned for identifying the appropriate regulatory and industry action.

In that respect, it is incumbent upon the commission to move forward both expeditiously and responsibly in identifying the lessons learned from the accident. The competent, professional NRC staff should analyze the lessons learned and obtain broad stakeholder input in the most meaningful way. The industry is fully committed to participate in stakeholder forums on this report, beginning at the July 28 public meeting at the NRC.

NEI and our industry partners are coordinating the industry's Fukushima response activities and are developing recommendations for the industry in seven "building blocks"—integrated organizations created to develop and execute action plans in specified areas of focus. The industry has already taken measures to enhance safety and preparedness. Nonetheless, the industry will ensure that no gaps exist in our response activities and that there is no duplication of effort among the industry organizations and companies. We recognize that to maintain the highest standard of safety and security, we must continually evolve and improve the industry's standards of practice, and adapt to events and new information that affect our industry.

The industry is concerned that the task force's use of phrases such as "patchwork of regulatory requirements" undermines the comprehensive body of regulatory requirements imposed by the NRC, the agency's extensive inspection and oversight process, and the excellent safety performance at the industry's 104 reactors. As the task force report notes, operation of U.S. nuclear energy facilities does not pose a risk to public safety. In fact, the NRC has not identified any significant adverse trends in safety at U.S. reactors in its last 10 years of reporting.

The industry certainly agrees that the safety benefits of new requirements should be used to prioritize and integrate any new requirements with those currently being considered by the agency, such as work hours for plant workers, cyber security and fire protection. In doing so, the NRC should use its formal process for evaluating the resource implications of new or revised regulatory requirements both on the agency staff and nuclear energy facility staff. It might be useful if the NRC prioritized activities in an integrated schedule that includes all new requirements being developed or implemented over the next five years.

The task force report stated that all of its recommendations should be considered within the "adequate protection" standard. However, the basis for the recommendations contained in the task force report requires more expansive and detailed analyses to ensure that they actually address the lessons learned from the Fukushima accident. After the necessary and appropriate analyses are conducted by the NRC staff, the commission should expect the staff to justify the value of any new or revised requirements consistent with NRC standard practice. If any proposed new requirements are justified within the adequate protection standard, the commission should review these on a case-by-case basis.

The industry is fully committed to enhancing safety at America's nuclear energy facilities. NEI and its members look forward to participating in the rigorous and systematic process for public comment and review of the task force recommendations. There are differences between the Japanese and U.S. approaches both in operation of nuclear energy facilities and the regulatory oversight of these facilities. The agency should recognize these as well as still-emerging information from Japan as we move forward to address the lessons learned.

Sincerely,

Marvin S. Fertel

c: The Honorable Kristine L. Svinicki, Commissioner, U.S. Nuclear Regulatory Commission
The Honorable William D. Magwood, IV, Commissioner, U.S. Nuclear Regulatory Commission
The Honorable George Apostolakis, Commissioner, U.S. Nuclear Regulatory Commission
The Honorable William C. Ostendorff, Commissioner, U.S. Nuclear Regulatory Commission
Mr. R. William Borchardt, Executive Director for Operations, U.S. Nuclear Regulatory Commission

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NUCLEAR ENERGY INSTITUTE

Marvin S. Fertel
PRESIDENT AND CHIEF EXECUTIVE OFFICER

August 1, 2011

The Honorable Barbara Boxer
Chairwoman
Committee on Environment & Public Works
United States Senate
410 Dirksen Senate Office Building
Washington, DC 20510

The Honorable James Inhofe
Ranking Member
Committee on Environment & Public Works
United States Senate
456 Dirksen Senate Office Building
Washington, DC 20510

Dear Chairwoman Boxer and Ranking Member Inhofe:

I understand that, in advance of tomorrow's hearing on the Nuclear Regulatory Commission's 90-Day Report, that some have alleged that operators of U.S. nuclear power plants oppose the recommendations in the report. That is absolutely untrue.

The U.S. nuclear power industry welcomes the 90-Day Report. Although we do not yet know with certainty all that happened at the Fukushima-Daiichi plants, we believe the report raises the right set of issues that need to be examined with regard to U.S. plants.

Further, as Commissioner Ostendorff has detailed and other Commissioners have also made clear in their votes on the 90-Day Report, we believe there are some actions that should be taken in the near-term. Industry immediately took some of those actions in the days after the events in Japan and is fully prepared to implement a number of others in the next 6 to 12 months.

All four Commissioners that have voted on the Task Force Report also indicated that they believe the report raises additional issues that will need to be addressed through rulemaking or other processes that will require more time. It is important that the Commission proceed with deliberate speed to issue a staff requirements memorandum to the Commission staff laying out the process to consider and disposition the task force recommendations.

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I encourage the Committee to use tomorrow's hearing to stress the importance of the Commission acting quickly to issue the staff requirements memorandum so that the Commission staff, industry, and other stakeholders can engage and proceed expeditiously.

Sincerely,

Marv S Fertel

Marv Fertel

c: Members of the Committee
Members of the Commission
William Borchardt, Executive Director for Operations

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