THE FUTURE OF FOSSIL: ENERGY TECHNOLOGIES LEADING THE WAY

JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY &
SUBCOMMITTEE ON ENVIRONMENT

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

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July 17, 2018

THE FUTURE OF FOSSIL: AENERGY TECHNOLOGIES LEADING THE WAY

TUESDAY, JULY 17, 2018

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY AND
SUBCOMMITTEE ON ENVIRONMENT,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittees met, pursuant to call, at 10:10 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Randy Weber [Chairman of the Subcommittee on Energy] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515-6301
(202) 225-6371
www.science.house.gov

The Future of Fossil: Energy Technologies Leading the Way

Tuesday, July 17, 2018
10:00 a.m.
2318 Rayburn House Office Building

Witnesses

Dr. Roger Aines, Senior Scientist, Atmospheric, Earth and Energy Division, Lawrence Livermore National Laboratory

Dr. Klaus Brun, Program Director, Machinery Program, Fluids & Machinery Engineering Department, Southwest Research Institute

Ms. Shannon Angielski, Executive Director, Carbon Utilization Research Council

Mr. Jason Begger, Executive Director, Wyoming Infrastructure Authority

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

July 10, 2018

TO: Members, Subcommittee on Energy, Subcommittee on Environment

FROM: Majority Staff, Committee on Science, Space, and Technology

SUBJECT: Joint Subcommittee Hearing: "The Future of Fossil: Energy Technologies Leading the Way"

The Subcommittee on Energy and the Subcommittee on Environment of the Committee on Science, Space, and Technology will hold a joint hearing titled *The Future of Fossil: Energy Technologies Leading the Way* on Tuesday, July 17, 2018 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building.

Hearing Purpose:

The purpose of this hearing is to explore next generation fossil power technologies and discuss technology solutions that improve efficiency and reduce emissions for fossil fuel power plants. The hearing will also explore innovation and potential application of carbon utilization technologies.

Witness List

- **Dr. Roger Aines,** Senior Scientist, Atmospheric, Earth and Energy Division, Lawrence Livermore National Laboratory
- **Dr. Klaus Brun,** Program Director, Machinery Program, Fluids & Machinery Engineering Department, Southwest Research Institute
- **Ms. Shannon Angielski,** Executive Director, Carbon Utilization Research Council
- **Mr. Jason Begger,** Executive Director, Wyoming Infrastructure Authority

Staff Contact

For questions related to the hearing, please contact Jimmy Ward or Ben Traynham of the Majority Staff at 202-225-0222.

Chairman WEBER. The Committee on Science, Space, and Technology will come to order.

Without objection, the Chair is authorized to declare recess of the Subcommittees at any time.

Good morning, and welcome to today's hearing titled, "The Future of Fossil: Energy Technologies Leading the Way." I now recognize myself for five minutes for an opening statement.

This morning, we will examine the status of the early-stage research performed by industry, nonprofit institutes, and the Department of Energy national laboratories to enable advancements in fossil energy technologies. Global demand for fossil fuels will hold steady in the near term and is projected to increase far into the future. Our abundant natural resources, including coal, oil, and natural gas, can and should be produced to meet this demand. However, these fuels should be utilized with efficient technologies that minimize the environmental impact.

Early-stage research funded by the Federal Government, coupled with efforts to develop new technologies by the energy industry, are critical to ensuring we can use our resources long into the future. Over the years, this partnership between the labs and industry has led to the development of advanced scrubber technologies to significantly reduce the release of NOx, SOx, and other unwanted byproducts from fossil-based power plants.

Because of this technology-led success, today, we can often focus on another byproduct of fossil power production, that being carbon dioxide. But unlike other emissions, carbon dioxide can potentially have a number of key uses in industrial applications. As our knowledge in chemistry advances, so does our ability to capture and repurpose carbon waste as an industrial product. These utilization technologies have the potential to convert carbon dioxide into building materials or even reuse CO_2 as part of the power generation cycle instead of steam.

Because of the potential benefits to this technology, industry is investing in research to advance carbon utilization. This industry engagement has advanced independently of any federal regulation and combines private-sector investment and the tools and technical assistance provided by national labs, state research facilities, as well as universities.

Early-stage research in the national laboratory system also supports the development of new energy production technologies. An example, at Lawrence Livermore National Laboratory, researchers have developed a 3–D printed polymer that uses bacteria to convert methane, the primary component of natural gas, into methanol at room temperature and pressure. This technology has the potential to reduce any methane leaked from natural gas production by cost-effectively capturing and converting it to liquid methanol at small scales. This research led by the national labs can now be taken up by industry to improve the extraction and efficient use of natural gas products. This partnership is a win-win for science, for energy, and for the environment.

However, in recent years, the use of our limited taxpayer research and development dollars has kind of shifted away from fundamental research like this to the support of large-scale technology demonstration projects, one that industry has the ability to fund on its own. The research community and the private industry would be better served if we focused federal investment on the early-stage research that has a proven track record of producing transformative energy technologies.

I want to thank our panel of witnesses for their testimony today, and I look forward to hearing what role Congress should play in advancing fossil energy research.

[The prepared statement of Chairman Weber follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
July 17, 2018

Media Contacts: Heather Vaughan, Bridget Dunn
(202) 225-6371

Statement by Chairman Randy Weber (R-Texas)

The Future of Fossil: Energy Technologies Leading the Way

Chairman Weber: Today, we will examine the status of the early-stage research performed by industry, non-profit institutes and the Department of Energy national laboratories to enable advancements in fossil energy technologies.

Global demand for fossil fuels will hold steady in the near-term and is projected to increase far into the future. Our abundant natural resources—including coal, oil and natural gas—can and should be produced to meet this demand.

However, these fuels should be utilized with efficient technologies that minimize the environmental impact. Early-stage research funded by the federal government coupled with efforts to develop new technologies by the energy industry are critical to ensuring we can use our resources long into the future.

Over the years, this partnership between the labs and industry has led to the development of advanced scrubber technologies to significantly reduce the release of NOx, SOx, and other unwanted byproducts from fossil-based power plants.

Because of this technology-led success, today we often focus on another byproduct of fossil power production—carbon dioxide (CO2).

But unlike other emissions, carbon dioxide can potentially have a number of key uses in industrial applications. As our knowledge in chemistry advances, so does our ability to capture and repurpose carbon waste as an industrial product.

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This research led by the national labs can now be taken up by industry to improve the extraction and efficient use of natural gas products. This partnership is a win-win for science, energy and the environment.

However, in recent years, the use of our limited taxpayer research and development dollars has shifted away from fundamental research like this to the support of large-scale technology demonstration projects—ones that industry has the ability to fund on its own.

The research community and the private industry would be better served if we focused federal investment on the early-stage research that has a proven track record of producing transformative energy technologies.

I want to thank our panel of witnesses for their testimony today and I look forward to hearing what role Congress should play in advancing fossil energy research.

###

Chairman WEBER. I now yield to the Ranking Member, Mr. Veasey.

Mr. VEASEY. Thank you, Mr. Chairman, for holding this hearing, and thank you to the witnesses for being here today.

Fossil fuels currently account for about 60 percent of our electricity generation in the United States, and they will likely continue to command a large market share of this for decades to come. Power plants are now the second-largest source of greenhouse gas emissions, just a bit behind the transportation sector.

Reducing these emissions and finding technology solutions to these realities is a very pressing challenge. It's going to require stable public investment in our academic institutions and national labs, alongside significant partnerships with the private industry.

That is why in May I introduced H.R. 5745, the bipartisan Fossil Energy Research and Development Act of 2018. I was joined by my colleagues Mr. McKinley from West Virginia and our committee's Ranking Member Ms. Johnson.

This bill would authorize critical activities within DOE's Office of Fossil Energy. This office is responsible for stewarding research to reduce emissions, improve efficiency, and mitigate the environmental impacts of energy generation from fossil fuels. A large portion of this research focuses on developing carbon-capture technologies and demonstrating the use and storage methods for the captured CO_2.

H.R. 5745 would authorize and expand research, development, and demonstration of these technologies for power plants, including large-scale pilot projects that would fill a vital gap in DOE's current portfolio of projects in this area.

The bill also authorizes R&D activities in carbon storage, rare earth elements, and carbon utilization, which I understand we will hear more about from Dr. Aines shortly. It also supports significant improvements in efficiency, including the development of supercritical CO_2 technologies, which I know we'll hear more about from Dr. Brun this morning.

In addition, the bill would launch important new initiatives in carbon dioxide removal, methane leak detection, mitigation, and carbon dioxide pipelines.

And finally, it would put in place key reforms to DOE's fossil energy lab, the National Energy Technology Laboratory, located in West Virginia and Oregon. Authorizing these technologies would also benefit the environment, our economy, and potentially provide technology solutions to global partners aiming to cut emissions.

The critical work authorized in this bill is supported by a diverse array of stakeholders, including representatives from industry, academia, labor, and environmental organizations. Two major U.S. coalition groups representing a large interested—representing a large group of interested stakeholders on these issues, the Carbon Utilization Research Council, represented by its Director Ms. Angielski is here today; and the Carbon Capture Coalition have endorsed this bill.

And without objection, Mr. Chairman, I would like to submit this letter of support for the bill from the American federal government Employees Union for the record.

Chairman WEBER. Without objection.

[The information appears in Appendix II]

Mr. VEASEY. In closing, I would like to strongly encourage all of my colleagues on the committee to consider cosponsoring H.R. 5745, and I look forward to discussing the best ways we can move these technologies with this excellent panel of witnesses that we have today.

And, Mr. Chairman, I yield back the balance of my time.

[The prepared statement of Mr. Veasey follows:]

OPENING STATEMENT
Ranking Member Marc Veasey (D-TX)
of the Subcommittee on Energy

House Committee on Science, Space, and Technology
Subcommittee on Energy
Subcommittee on Environment
"The Future of Fossil: Energy Technologies Leading the Way"
July 17, 2018

Thank you Mr. Chairman for holding this hearing and thank you to the witnesses for being here today.

Fossil fuels currently account for about 60% of electricity generation in the U.S., and they will likely continue to command a large share of this market for decades to come. Power plants are now our second largest source of greenhouse gas emissions, just a bit behind the transportation sector. Reducing these emissions and finding technology solutions to these realities is a pressing challenge. It requires stable public investment in our academic institutions and national laboratories alongside significant partnerships with private industry. This is why in May, I introduced H.R. 5745, the bipartisan Fossil Energy Research and Development Act of 2018. I was joined by my colleagues Mr. McKinley from West Virginia and our Committee's Ranking Member, Ms. Johnson, yet another very smart and distinguished Texan.

This bill would authorize critical activities within DOE's Office of Fossil Energy. This office is responsible for stewarding research to reduce emissions, improve efficiency, and mitigate the environmental impacts of energy generation from fossil fuels. A large portion of this research focuses on developing carbon capture technologies and demonstrating the uses and storage methods for the captured CO_2. H.R. 5745 would reauthorize and expand research, development, and demonstration of these technologies for power plants, including large-scale pilot projects that would fill a vital gap in DOE's current portfolio of projects in this area. The bill also authorizes R&D activities in carbon storage, rare earth elements, and carbon utilization – which I understand we'll hear more about from Dr. Aines shortly. It also supports significant improvements in efficiency including the development of supercritical CO_2 technologies – which I know we'll hear more about from Dr. Brun this morning. In addition, the bill would launch important new initiatives in carbon dioxide removal, methane leak detection and mitigation, and carbon dioxide pipelines. Finally, it would put in place key reforms to DOE's Fossil Energy laboratory, the National Energy Technology Laboratory, located in West Virginia, Pennsylvania, and Oregon.

Authorizing these technologies would benefit the environment, the U.S. economy, and potentially provide technology solutions to global partners aiming to cut emissions. The critical work authorized in this bill is supported by a diverse array of stakeholders – including representatives from industry, academia, labor, and environmental organizations. Two major U.S. coalition groups representing a large group of interested stakeholders on these issues – the Carbon Utilization Research Council, represented by its Director, Ms. Angielski, here today, and the Carbon Capture Coalition – have endorsed this bill. And without objection, I'd like to submit this letter of support for the bill from the American Federal Government Employees union for the record.

In closing, I'd like to strongly encourage all of my colleagues on the Committee to consider cosponsoring H.R. 5745. I look forward to further discussing the best ways we can move these technologies with this excellent panel of witnesses.

Thank you and I yield back.

Chairman WEBER. Thank you, sir.

I now recognize Mr. Biggs, Arizona. Chairman?

Chairman SMITH. Thank you—go on. I forgot. You go on.

Mr. BIGGS. Thank you, Mr. Chairman and Mr. Chairman.

Good morning, and welcome to today's joint Environment Subcommittee and Energy Subcommittee hearing on fossil energy technologies. I thank our witnesses for being here. I look forward to hearing their interesting testimony today after reading their submissions.

Today, we will discuss cutting-edge fossil energy technologies that will both advance our Nation's environmental interests, as well as maintain American energy dominance. Like it or not, power generated by fossil fuels is and will continue to be America's core source of base load electricity. Unfortunately, due to regulations and a media-garnered negative public perception, the fossil fuel industry is under constant attack. Moreover, these regulations result in more economic harm than environmental gain in the way of job loss and higher utility bills for hardworking Americans.

Today's hearing will focus on technologies that, when commercialized, can both boost the economy and clean our air for generations to come. The reality is that there is no reliable and affordable alternative to fossil-fuel-generated power at this time. As a result, fossil fuels will continue to support economic and infrastructure development both here in the United States and abroad.

As we learned from our recent hearing on climate adaptation, a strong economy and reliable infrastructure is necessary to protect against potential environmental harm. Shuttering a coal power plant in Arizona will not mitigate the effects of sea level rise in California. That effort requires advanced building materials and a reliable grid, all things made possible by fossil fuels.

The question remains: How do we balance the apparent need for fossil fuels with a call for lowering the amount of carbon dioxide in our atmosphere? We do that by incentivizing the creation of technologies that capture the carbon before it leaves the power station and developing innovative ways to use that captured carbon for commercial purposes.

Those technologies, known as carbon capture, utilization, and sequestration—or CCUS—present a win-win for America. Rather than be emitted into the atmosphere, CCUS gives us the opportunity to convert carbon dioxide into a useful commodity. Not only do these technologies allow for the continued viability of the existing fleet of fossil fuel plants, but they create the prospect for new industry sectors altogether.

While the Federal Government certainly plays a role in foundational research in this area, the private sector is best situated to innovate and scale up these technologies. One example we will hear more about today is the Wyoming Integrated Test Center, or ITC. The ITC is a public-private partnership that has received no federal funds. Located at the coal-powered Basin Electric Power Plant outside Gillette, Wyoming, the facility is set up as a testing site for researchers to scale up technologies designed to convert carbon dioxide into commercially viable products like building materials and plastics.

Facilities like the ITC are why America is the leader in CCUS technology. As the production and demand for fossil fuels continue to grow worldwide, it is essential for Congress to continue to encourage innovation in this area.

Again, I thank the witnesses for being here today. I look forward to learning more about their interesting work in government and the private sector.

With that, I yield back.

[The prepared statement of Mr. Biggs follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
July 17, 2018

Media Contacts: Heather Vaughan, Bridget Dunn
(202) 225-6371

Statement by Rep. Andy Biggs (R-Ariz.)

The Future of Fossil: Energy Technologies Leading the Way

Chairman Biggs: Good morning and welcome to today's joint Environment Subcommittee and Energy Subcommittee hearing on fossil energy technologies. I'd like to thank our witnesses for being here.

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Again, I want to thank the witnesses for being here today, and I look forward to learning more about the interesting work being done by the government as well as the private sector.

###

Chairman WEBER. Thank you, sir. The Chair now recognizes the gentlelady from Oregon, Ms. Bonamici.

Ms. BONAMICI. Thank you, Mr. Chairman.

Our Nation is facing a serious confluence of factors affecting our energy policy: a growing global demand for energy, a heavy reliance on fossil fuels, high energy prices, and climate change resulting from harmful emissions.

In 2015, the Energy Information Administration found that fossil fuel usage accounted for nearly 82 percent of all energy consumption in the United States. This was the lowest share in the previous 100 years but still demonstrates our dependence on fossil fuels.

The dangers to our climate and environment from the carbon emissions generated from fossil fuel production and use have been studied and confirmed. It is more important than ever that we develop a comprehensive national energy policy that includes a greater emphasis on investing more, not less, in research and development programs to improve efficiency and reduce emissions to keep our air and water clean.

In Oregon, we are leading the nation to decrease our reliance on fossil fuels with our robust renewable energy portfolio of solar and wind resources. By focusing our investments on renewable resources, we not only protect our environment, but we also have the opportunity to support new industries, new jobs, and innovative small businesses that are developing clean-energy technologies. During the transition, and for States not making similar commitments yet, fossil fuels must be used in a responsible way that mitigates environmental harm.

The Department of Energy's Office of Fossil Energy supports research on ways to reduce the negative environmental effects of using and developing fossil energy resources. This includes improvements to the efficiencies of a wide range of fossil and non-fossil-fueled power plants through the advancements of technologies such as supercritical carbon dioxide power cycles. Much of this cutting-edge research is conducted at DOE laboratories, including the National Energy Technology Laboratory, NETL, in Albany, Oregon. The lab is also advancing affordable carbon-capture technologies that reduce emissions and use captured carbon dioxide to increase domestic oil production from depleted oil fields.

Despite these innovative efforts at the Department of Energy, this Administration has sent inconsistent messages about fossil energy technologies. President Trump has highlighted the need for clean coal and has worked to bolster fossil industries but has simultaneously attempted to slash funding for the critical federal research supported by the Office of Fossil Energy in his fiscal year 2019 budget request.

As a result of strong collaborative efforts between federal and nonfederal partners, the United States is considered a leader in the development of various innovative fossil energy technologies such as carbon capture and storage. Underfunding these activities could ultimately cede American leadership in the rapidly developing low-carbon economy.

As members of the Science Committee, we should be encouraging the Department of Energy to continue supporting unparalleled research into environmental mitigation strategies for fossil fuels that would otherwise not be pursued by the private sector. Until we regulate carbon emissions in the United States to drive innovation in the private sector, government-sponsored research is critical to fill the gaps in the market. Through these investments, there is tremendous opportunity for the United States to promote a healthier environment and become a leading exporter rather than importer of the next generation of fossil energy technologies.

I am pleased to see a well-rounded witness panel today to discuss the successful partnership between federal, state, and private-sector researchers in this field. I look forward to learning more about current technologies used to mitigate the environmental effects associated with the production and use of fossil fuels and the innovations that can support a new national energy policy.

Thank you, Mr. Chairman. I yield back the balance of my time.

[The prepared statement of Ms. Bonamici follows:]

<u>OPENING STATEMENT</u>
Ranking Member Suzanne Bonamici (D-OR)
of the Subcommittee on Environment

House Committee on Science, Space, and Technology
Subcommittee on Energy
Subcommittee on Environment
"The Future of Fossil: Energy Technologies Leading the Way"
July 17, 2018

Thank you, Mr. Chairman. Our nation is facing a serious confluence of factors affecting our energy policy: a growing global demand for energy, a heavy reliance on fossil fuels, high energy prices, and climate change resulting from harmful emissions. In 2015, the Energy Information Administration found that fossil fuel usage accounted for nearly 82 percent of all energy consumption in the U.S. This was the lowest share in the previous 100 years, but still demonstrates our dependence on fossil fuels.

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Thank you, Mr. Chairman, I yield back.

Chairman WEBER. Thank you, ma'am. The Chair now recognizes the Chairman of the full committee, Mr. Lamar Smith of Texas.

Chairman SMITH. Thank you, Mr. Chairman.

Energy produced from fossil fuel is abundant, affordable and vital to America's security and competitiveness. As global demand for fossil fuel energy increases, America is on tap to become a net energy exporter.

The research done at Department of Energy national laboratories is vital to increasing the fossil fuels' efficiency and reducing environmental impacts of this vital power source. Basic science discoveries at DOE national labs have led to a range of technological innovations used by private industry in fossil energy production and fossil power systems.

From horizontal drilling and hydraulic fracturing, to improved sensors and geologic mapping, we've seen dramatic improvements in fossil fuel production technology that was developed from research conducted in the DOE lab system. For example, field engineers today are using augmented reality and virtual reality technologies in maintenance, operations, and exploration of reservoirs. Using this technology in the field can reduce the environmental footprint of energy production and increase oil and gas production as well.

And in fossil power production, new approaches like the use of supercritical carbon dioxide power systems can replace the use of steam power, improving efficiency and potentially producing virtually carbon-free energy. The Southwest Research Institute, located near my district in San Antonio, is partnering with DOE to lead early-stage research efforts in developing these supercritical CO_2 systems.

In the past, the DOE's Office of Fossil Energy Research and Development programs focused primarily on reducing emissions from fossil power. While research on carbon capture, storage, and sequestration technologies remains a priority, there is also potential to research ways to use carbon as an energy resource, rather than only considering it as a waste product.

At the National Energy Technology Laboratory, DOE is funding basic research to create usable substances from carbon waste, such as concrete or plastics. If these techniques are commercialized by industry, they could provide added revenue for fossil power plants, making carbon capture a cost-effective method to reduce emissions.

DOE's early-stage research should focus on developing a broad range of innovative technologies to improve the efficiency and effectiveness of fossil fuels, allowing us to use all our natural resources long into the future.

I look forward to hearing about the promise of fossil energy technologies from our witnesses today and how DOE-funded research supports technological innovations that improve the efficiency, environmental impact, and safety of fossil fuels.

And I yield back, Mr. Chairman.

[The prepared statement of Chairman Smith follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
July 17, 2018

Media Contacts: Heather Vaughan, Bridget Dunn
(202) 225-6371

Statement by Chairman Lamar Smith (R-Texas)

The Future of Fossil: Energy Technologies Leading the Way

Chairman Smith: Energy produced from fossil fuel is abundant, affordable and vital to America's security and competitiveness. As global demand for fossil fuel energy increases, America is on tap to become a net energy exporter.

The research done at Department of Energy (DOE) national laboratories is vital to increasing the fossil fuels' efficiency and reducing environmental impacts of this vital power source.

Basic science discoveries at DOE national labs have led to a range of technological innovations used by private industry in fossil energy production and fossil power systems.

From horizontal drill and hydraulic fracturing, to improved sensors and geologic mapping, we've seen dramatic improvements in fossil fuel production technology that was developed from research conducted in the DOE lab system.

For example, field engineers today are using augmented reality and virtual reality technologies in maintenance, operations and exploration of reservoirs. Using this technology in the field can reduce the environmental footprint of energy production and increase oil and gas production.

And in fossil power production, new approaches like the use of supercritical carbon dioxide power systems can replace the use of steam power, improving efficiency and potentially producing virtually carbon-free energy. The Southwest Research Institute, located in my district, is partnering with DOE to lead early stage research efforts in developing these supercritical CO2 systems.

In the past, the DOE's Office of Fossil Energy Research and Development programs focused primarily on reducing emissions from fossil power. While research in carbon capture, storage and sequestration technologies remains a priority, there is also potential to research ways to use carbon as an energy resource, rather than only considering it as a waste product.

At the National Energy Technology Laboratory (NETL), DOE is funding basic research to create usable substances from carbon waste, such as concrete or plastics. If these techniques are commercialized by industry, they could provide added revenue for fossil power plants, making carbon capture a cost-effective method to reduce emissions.

DOE's early-stage research should focus on developing a broad range of innovative technologies to improve the efficiency and effectiveness of fossil fuels, allowing us to use all our natural resources long into the future.

I look forward to hearing about the promise of fossil energy technologies from our witnesses today and how DOE-funded research supports technological innovations that improve the efficiency, environmental impact and safety of fossil fuels.

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Chairman WEBER. Thank you, sir. And the Chair now recognizes the gentlelady from Texas, the Ranking Member of the full Committee, Ms. Johnson.

Ms. JOHNSON. Thank you very much, Mr. Chairman, and let me welcome our witnesses. I want to express my appreciation to both Chairman Weber and Chairman Biggs and our distinguished Ranking Members for holding this hearing to discuss the future of fossil energy.

Certainly, we have seen how advances in science and engineering can produce large-scale economic value in this sector, and historically, our federal R&D agencies have played a major historic role in this process.

Just over a decade ago, we had a little—little idea of the fossil resources that would be available to us today. However, due to some critical research investments made by the Department of Energy over 40 years ago, coupled with rising oil prices in recent decades, the United States underwent the shale gas revolution that brought major natural gas resources online, and with it, a sharp increase in domestic oil production.

That DOE program wrapped up in the early '90s when a private company took that federally supported research and used it to trigger the oil and gas boom we see today. I think my colleagues would agree that that is the model for DOE's energy technology programs we all hope to see, federal investments shepherding transformational technologies to the marketplace, even when the endpoint is not clear at the beginning of the process.

That brings us to what should be the fundamental question we consider today: Where should the Department of Energy be investing its limited dollars in this area? If the standard of identifying a federal role rests on whether the private industry has the capacity to invest in R&D, then I think the answer to the question is that DOE should focus its investments on reducing and wherever possible eliminating the environmental impacts of the production and use of these resources. At present, there is unfortunately little incentive for industry to spend major R&D dollars to protect the environment and even less incentive in the private sector to prevent the most devastating potential impacts of climate change.

This is why I am so pleased to cosponsor H.R. 5745, the bipartisan Fossil Fuel Research and Development Act of 2018, which Ranking Member Veasey and Mr. McKinley and I introduced in May. This bill would reauthorize and expand important activities to develop and scale up innovative carbon capture, utilization, and storage technologies. It would also launch vital new initiatives on carbon dioxide removal and methane leak detection and mitigation, among other areas.

In all likelihood, our society will continue to use and develop our fossil energy resources for at least several more decades, so these technologies will be absolutely critical to minimizing the harm they would otherwise cause to our public health and to the environment.

Before I close, I would note that I am surprised that we are holding a hearing on DOE's fossil energy technology development activities without inviting DOE's Assistant Secretary for Fossil Energy to testify. It seems to me that it would be important for us to ask him to provide a better explanation for why the Administration is proposing a 31 percent cut to DOE's fossil energy research and development activities. This is in stark contrast to the stated positions of the President, who has been praising clean coal and vowing to end a supposed war on clean coal throughout his time in office so far. The rhetoric is not matched by the necessary resources, and this committee needs to know why not.

So I hope that we will have Assistant Secretary Winberg before our committee to discuss these issues further in the near future. And I look forward to working with the Administration and my colleagues on both sides of the aisle in the months ahead to steer a better course as we aim to accelerate the development and deployment of these next-generation technologies that could significantly improve our environment, our health, and our Nation's economy.

Thank you and I yield back.

[The prepared statement of Ms. Johnson follows:]

<u>OPENING STATEMENT</u>
Ranking Member Eddie Bernice Johnson (D-TX)
House Committee on Science, Space, and Technology

Subcommittee on Energy
Subcommittee on Environment
"The Future of Fossil: Energy Technologies Leading the Way"
July 17, 2018

Good morning and welcome to our witnesses. Thank you, Chairman Weber and Chairman Biggs, for holding this hearing to discuss the future of fossil energy.

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Thank you and I yield back.

Chairman WEBER. I thank the gentlelady.

I will now introduce our witnesses. Our first witness today is Dr. Roger Aines, Chief Scientist at Lawrence Livermore National Laboratory, LLNL's Energy Program and Senior Scientist in the Chemistry, Materials, Earth, and Life Science Directorate. Dr. Aines has been at LLNL for over 30 years working on nuclear waste disposal, environmental remediation, and management of carbon emissions. He previously led LLNL's carbon management program, which takes an integrated view of the energy climate and environmental aspects of carbon-based fuel production and use.

Dr. Aines holds a bachelor of arts in chemistry from Carleton College and a Ph.D. in geochemistry from the California Institute of Technology. Welcome, Dr. Aines.

I now recognize Chairman Smith to introduce our second witness.

Chairman SMITH. Thank you, Mr. Chairman.

It's a privilege to introduce Dr. Klaus Brun, the Machinery Program Director at Southwest Research Institute located in San Antonio.

Southwest Research Institute specializes in advancing science and applying technology to benefit government, industry, and individual American lives.

Dr. Brun leads an organization of more than 60 scientists who focus on research and development for the energy industry. He is internationally recognized for his expertise in energy systems, power generation, and turbomachinery.

Dr. Brun holds a bachelor of science from the University of Florida and a master of science and Ph.D. both in mechanical engineering from the University of Virginia. He is a Fellow of the American Society of Mechanical Engineers and the current Associate Editor of their Journal of Engineering for Gas Turbines and Power.

Dr. Brun, we welcome you and look forward to your testimony.

Chairman WEBER. Thank you, Mr. Chairman.

Our next witness is Ms. Shannon Angielski, the Executive Director of the Carbon Utilization Research Council, CERC. Prior to her current employment, Ms. Angielski served as the Associate Director—do we pronounce that CERC, C–E–R–C? Okay. She is a member of the National Coal Council the American League of Lobbyists, and the Environmental Law Institute and serves on the board of the Washington Coal Club.

She earned a bachelor of art in political science and international affairs from the University of New Hampshire and a master of science in environmental and public policy from Johns Hopkins University. Welcome.

Our final witness today is Mr. Jason Begger, the Executive Director of the Wyoming Infrastructure Authority. Mr. Begger, I understand your wife is very pregnant and due just almost any time. We appreciate you choosing to be here. I guess you prove that beggars can be choosers, so we'll see if she still lets you back in in case that baby starts early, so we appreciate—prayers and blessings for that young one's arrival.

Prior to this, Mr. Begger worked for two members of Montana's congressional delegation focusing on Bureau of Reclamation water projects and Department of Energy Office of Fossil Energy funding.

He went on to serve as the Vice President of the Petroleum Association of Wyoming and then Manager of Government Affairs for Cloud Peak Energy.

Mr. Begger holds a bachelor of art in history from Montana State University Billings and a master of business administration from the University of Denver.

Again, welcome this morning. We hope you the best, you and your wife the best so—I now recognize Dr. Aines for five minutes to present his testimony.

TESTIMONY OF ROGER DR. ROGER AINES, SENIOR SCIENTIST, ATMOSPHERIC, EARTH AND ENERGY DIVISION, LAWRENCE LIVERMORE NATIONAL LABORATORY

Dr. AINES. I've submitted my full statement to the Committee, which I ask to be made part of the hearing record. If I may, I'll now summarize a brief opening statement.

Thank you, Chairman Smith, Ranking Member Johnson, Chairman Weber, Ranking Member Veasey, and Chairman Biggs and Ranking Member Bonamici, for this opportunity to share our insights into the current status and future of fossil energy and carbon capture, utilization, and storage.

My name is Roger Aines. I'm the Chief Scientist of the Energy Program at Lawrence Livermore National Lab. I've worked on fossil fuel technology and carbon management for 20 years.

At Lawrence Livermore Lab we're focused on tomorrow's clean energy system. This testimony provides an update on emerging fossil energy technologies, including carbon capture, carbon storage, carbon utilization, and advanced energy systems, finally removing carbon dioxide from the atmosphere. It includes an assessment of the current state of CO_2 utilization in American industry. This current state foreshadows a future in which natural gas and CO_2 become feedstocks for valuable products, just as we've noted many times in the opening statements, creating an economic opportunity for all regions of the United States using our abundant resources and new technology.

The mission of the Department of Energy's national laboratories is to advance science and technology that addresses issues of today to anticipate pending national and global challenges and help provide solutions to them in close partnership with companies that can bring those solutions to the market. The need for efficient fossil fuel technologies that can provide an engine for enhanced U.S. competitiveness has led to DOE research and analysis conducted at Lawrence Livermore Lab, as well as other national labs.

Today, technology is rapidly transforming fossil energy, but despite enormous progress in carbon capture, carbon dioxide is still not being managed in the power and industrial sectors because that is still too expensive. However, many businesses are eager to turn carbon dioxide into products. Turning a waste into a feedstock will help solve the cost problem. This is called carbon utilization or I like to call it carbon recycling, and it's poised to become a major industry.

Last month in Livermore, we held a roundtable discussion with 20 corporations ranging from Exxon to 3M to Nike, all who were interested in how they could improve their products with materials made from carbon dioxide. This is a ripe area for research with much work going on today at university labs such as Stanford and Rice Universities. This is an opportunity for new technology to aid multiple industrial and power generation actors who want to manage their carbon dioxide. New technology like 3–D printing, as Mr. Weber mentioned, will be important to that transition.

Natural gas will also be an important part of the transition to what we call the new carbon economy where carbon-based products that we use every day are increasingly made from simple feedstocks like carbon dioxide, natural gas, and electricity. The chemical industry will be the first to be impacted by the ease of using them to make the fibers and plastics that are part of our lives. New industrial centers will spring up in places where carbon dioxide, electricity, and natural gas are abundant and cheap such as the center of the country.

An important innovation is combining biology with 3–D printing. My laboratory works with the National Renewable Energy Laboratory to use engineered bacteria that they create, and we then 3–D print, along with a binder, to actually make the reactor out of the bacteria. Natural gas flows in and in our most advanced case lactic acid, a valuable precursor for synthetics, flows out. The bugs do all the work.

These kinds of new technology options will also allow us to address the challenge of removing the excess carbon dioxide from the atmosphere. A new carbon economy that values carbon dioxide as a feedstock and not a waste will help with this task. Much new science and technology development will be required and is just beginning today.

The United States is poised to be the leader in the use of CO_2 and natural gas for new carbon products, a new carbon economy. This will create new economic opportunity and improve national security as it makes us more energy self-sufficient. Development and demonstration of innovative fossil technologies will be the key to that process. Because energy and the necessary feedstocks—carbon dioxide and natural gas—are abundant in the central United States, we anticipate that new industries will thrive there.

Both basic research and development and transfer of that research to corporate users will be important accelerators for the new carbon economy. That research and development done by national laboratories strives to bring that vision to fruition.

Thank you very much.

[The prepared statement of Dr. Aines follows:]

House Science and Technology Committee

The Future of Fossil: Energy Technologies Leading the Way

July 17, 2018

Dr. Roger D. Aines, Lawrence Livermore National Laboratory

Written Testimony

Thank you for giving me this opportunity to share our insights into the current status and future of fossil energy and carbon capture, utilization, and storage. My name is Roger Aines and I am the Chief Scientist of the energy program at Lawrence Livermore National Laboratory (LLNL).

This testimony provides an update on emerging fossil energy technologies, including the status of *carbon capture, carbon storage, carbon utilization, advanced energy systems,* and *removing carbon dioxide from the atmosphere*, with emphasis and focus on CO_2 utilization and carbon removal. It includes an assessment of current technologies and their readiness, activities in technology development at my laboratory (LLNL), and the current state of CO_2 utilization in American industry. This current state foreshadows a future in which natural gas and CO_2 become feedstocks for valuable products, creating an economic opportunity for all regions of the United States by using abundant resources and new technology.

The technology to manage CO_2 is already deployed and operating, and functions as designed. New technologies for converting CO_2 into materials we use every day are developing rapidly. These developments provide new possibilities for commercial enterprise in the US and opportunities for commercial and technical leadership by our country. Innovation lies at the heart of this new carbon economy, and both basic and applied R&D are needed to take best advantage of the opportunities in this competitive and dynamic environment. An exciting example of the science and technology that is sure to drive new economic growth in CO_2 utilization is additive manufacturing, or 3-D printing, which is already beginning to revolutionize U.S. manufacturing. It will be a major technology component of this new landscape.

Demand for low-carbon energy continues to grow worldwide, with investment of nearly $400B in 2015 and 2016. Carbon capture, use, and storage (CCUS) remains a growing, but underutilized element in the low-carbon economy. CCUS is a technology category that includes carbon capture and storage, CO_2 enhanced oil recovery (EOR), CO_2 conversion and utilization, and even carbon removal technology (so called "negative emissions" approaches that pull CO_2 from the air and oceans). CCUS technologies provide commercial and environmental opportunities for companies, communities, and governments, particularly in parts of the country where CO_2 and natural gas are readily available, and electricity is inexpensive. This is particularly applicable to the center of the country.

Technical progress in CCUS is significant, but there is unrealized potential to manage carbon emissions. Today, 16 commercial CCUS plants operate worldwide, and with six more planned, 22 will be operating by 2020. These include power and industrial projects, new build and retrofits, and both CO_2-EOR and saline storage. More than a third of them are located in North America. Costs have come down, substantially through R&D by DOE Fossil Energy. In some sectors, like heavy industry (e.g., refining, cement manufacture), CCUS is the only option available at scale today for carbon management.

The mission of the Department of Energy's national laboratories is to advance science and technology that addresses issues of today, anticipate important pending national and global challenges, and help provide solutions to them. Much effort is focused on developing new technologies in close partnership with companies that can bring these technologies to market. The need for more efficient fossil fuel technologies that can provide an engine for enhanced US competitiveness have led to DOE research and analysis conducted at LLNL and other national labs.

Grounded in our experience in novel materials and modeling and simulation, LLNL has been funded to work for nearly two decades on CCUS. LLNL has been a partner in many of the carbon capture and sequestration projects nationally and globally and has developed analysis tools and early-stage technologies for CO_2removal from flue gas, air, and oceans. Recently, this effort has expanded to include conversion of CO_2 to useful products such as methanol and ethylene.

At LLNL we are focused on tomorrow's clean fossil energy system. I would like to comment on five areas of our work that are critical for a strong energy future: **carbon capture, carbon storage, carbon utilization, advanced energy systems,** and **removing carbon dioxide from the atmosphere.**

Carbon Capture affects our ability to use and manage carbon dioxide. We need to be able to capture CO_2 from flue gas in power plants and heavy industry. LLNL has worked in this area for ten years. We are focused on reducing the cost of carbon capture by reducing the capital expense of capture systems. LLNL is funded by the Fossil Energy Program to develop new carbon capture approaches that use additive manufacturing to make systems that are more efficient. Additive manufacturing can make capture equipment smaller, which can reduce the capital investment. Because capital costs can be half of the lifetime cost of a CO_2 management system, we believe that capital cost reductions are the best target for reducing the cost of carbon management.

Natural gas will grow in importance as our nation moves to use its extraordinary resources of this fossil fuel to create efficient industry and power. The technology that DOE has developed for coal-fired systems can also be applied to natural gas systems but has not been tested at large scale. There is a need to transfer that DOE knowledge to industrial natural gas users.

In **Carbon Storage** LLNL provides the most advanced 3-D fracture mechanics modeling for industrial partners to help them manage the risk of induced seismicity for underground carbon sequestration projects, hydraulic fracturing operations, and enhanced oil recovery. We are particularly interested in engaging the US oil industry, including independent producers, by taking advantage of their skills, workforce, and economic desire to make CO_2

storage a reality. For example, the Mt. Poso Cogeneration Company LLC is the largest biomass fueled power plant in California. It is located on an oil field with a depleted portion potentially suited for CO_2 storage. The geology there seems to be good and the Mt. Poso power plant may be one of several good sources of CO_2 for storage. The economic benefits from the 45Q storage tax credit and the California low-carbon fuel standard make this an attractive option that the site partners are considering. This is an excellent example of industry willing to step up, but in the design phase they will need help absorbing the knowledge developed in DOE programs to date. LLNL is working with them to do that and to help determine if CO_2 storage is a safe and economical option for them.

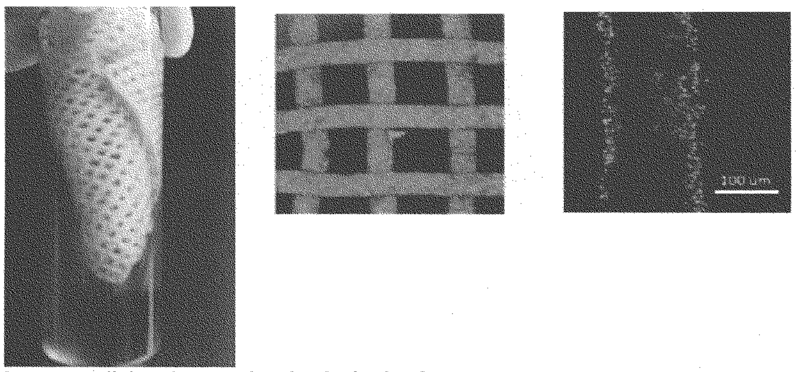
Carbon Utilization (or as some call it, *carbon recycling*) is poised to become a major new industry in the United States. Last month twenty companies from Exxon to 3M to Nike attended our workshop in Livermore for corporations interested in this new way to use CO_2. All of them are interested in how their products can be improved with materials fabricated from CO_2. We will be releasing a report on the conclusions from this workshop in the next few weeks. This is an area ripe for basic research, and not ready to jump to major production yet. Most of the work in this area is going on in university labs (like Pulickel Ajayan's at Rice University and Tom Jaramillo's at Stanford University), where the basic science of the reactions is being worked out.

In the Texas to Iowa corridor, *CO_2 is an abundant feedstock*, and the new wind turbines in that region routinely sell their power on the wholesale market for less than 2 cents a kilowatt hour. New industries can use that electricity and CO_2 to make exactly the desired chemical product in high yield, and they will not need much of the expensive separations equipment currently required for production of chemicals. When you look at a refinery or chemical plant today, most of that complex maze of equipment is for purifying the final product. By using simple feedstocks like carbon dioxide and natural gas, new factories can make our carbon products like textiles, plastics, and even fuels.

Wyoming has led the way in CO_2 utilization efforts with development of a CO_2 test center where entrepreneurs can demonstrate their new technologies. This kind of support for technology innovation will speed implementation of these new technologies.

The concrete and carbon fiber industries are also on the forefront of finding new economical uses of CO_2. *Concrete can be made stronger by adding CO_2* to it, and a number of companies are pursuing this goal including New Jersey's Solidia, which makes stronger precast concrete items with CO_2. Interestingly, one of Solidia's major business challenges is having an assured supply of CO_2 so that they can take on major contracts. Carbon fiber is just starting to be made from CO_2 in the laboratory, as are carbon nanotubes and other exotic materials for the light-weighting and electronics industries. C4 Composites in Santa Monica, CA, is working to make carbon fiber directly from natural gas, while simultaneously making hydrogen gas for use in chemicals or as fuel.

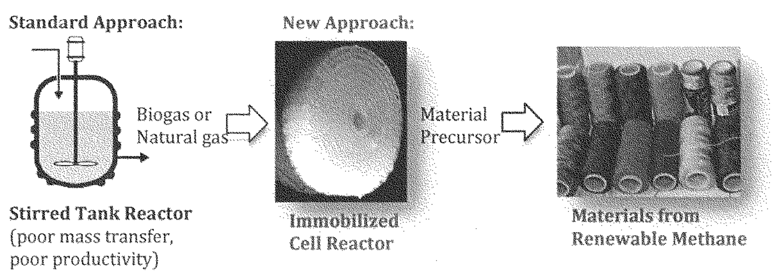
Additive manufacturing, or 3-D printing, is a game-changing innovation that allows complicated products to be built in ways that can't be done by conventional manufacturing. Additive manufacturing is very important for using CO_2 in new industrial processes. At LLNL we use 3-D printing to create chemical reactors that combine the natural gas, CO_2, and water in the exact proportions and perfect conditions to make a desired product. We can even use bacteria that have been modified to make the product we want and *build the reactor out of those bacteria* (along with a binder to hold them in place). Working with the National Renewable Energy Lab (NREL), which designs and supplies the bacteria, we have made reactors that produce valuable organic acids (like lactic acid) and methanol from natural gas.

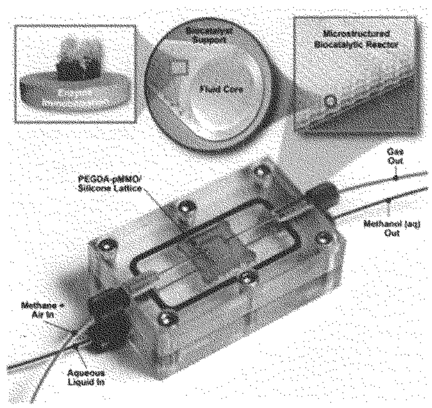


Live yeast cells have been combined with a binder, then put in a 3-D printer to make the fabric at left. The green color shows the location of the cells in the fabric. This material converts sugar to ethanol. The cells are alive and reproduce in the printed material: the reactor is a living thing. This technology could dramatically change the way chemicals and bioproducts are made.

These reactors will be the heart of new chemical plants building products from CO_2 and natural gas. The early products that companies are interested in are high-value organic chemicals that are best made by living organisms. This new reactor technology will create new businesses and jobs in the United States. They could also be used to convert small sources of natural gas into methanol, a liquid, that can be collected and transported in trucks, turning waste into a valuable resource.

These technologies are part of an LLNL program to use abundant energy resources to make new products. We are investigating the use of electricity to convert carbon dioxide and water to ethylene, the most abundant chemical feedstock. This could enable distributed generation of ethylene in parts of the United States where CO_2 is abundant and electricity is inexpensive today (much of the central part of the country).





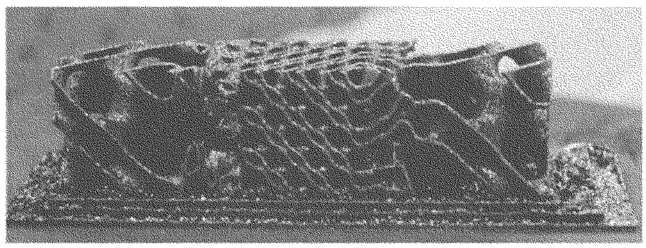
Additive manufacturing is an important part of utilizing CO_2 to make products. It allows us to balance many factors to get pure products. In this chemical reactor the cell wall of bacteria called *methanotrophs* are printed into the polymer walls of the device. The enzymes in those cell wells convert natural gas to methanol, a valuable industrial chemical. No added electricity or heat is needed. *Natural gas flows in, methanol flows out.*

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.

Looking to the future, LLNL sees great promise in revolutionary new technologies 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 valuable products. We see this industry as potentially enormous, possibly of a size and scale comparable to today's agriculture, oil and gas, or power sectors.

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

Advanced Energy Systems operate at high temperatures and pressures to achieve their high efficiency. Supercritical CO_2 systems that use highly pressurized CO_2 instead of water to drive turbines are a huge step change that can make America's power more efficient using our abundant natural gas. One of the most remarkable examples of this is NetPower,[2] a North Carolina-based company that uses "Allam cycle" combustion - oxygen-fired natural gas turbines that use supercritical CO_2. The NetPower system costs the same as a natural gas power block but produces more power and captures 100% of the CO_2. A pilot demonstration[3] near Houston has finished construction and begun testing—it should be fully operational in fall 2018, with Exelon, Chicago Bridge and Iron, and Toshiba as commercial partners.



This is the first Inconel 3-D printed heat exchanger, made at LLNL for the DOE's advanced energy systems program. Devices like this will allow higher-temperature and more efficient energy systems, while making economical use of valuable materials like nickel stainless steels, reducing the capital cost of new energy systems.

The very high efficiency with which the NetPower plant turns natural gas into electricity relies on high temperature components made of nickel steel. This metal is hard to machine and weld but at LLNL we are printing these components using laser 3-D printing. This allows us to work with the difficult nickel alloys and create unique shapes that can only be done by building the part up from powder instead of machining a metal block.

Carbon Removal from the atmosphere is the long-term challenge. The climate models tell us that in order to achieve a future with no more than two degrees of warming, we will need to remove billions of tons of CO_2 from the atmosphere. The United States is already testing carbon removal at the Archer Daniels Midland ethanol plant in Decatur, Illinois where the CO_2 from fermenting corn is captured and injected deep underground - *the first large-scale carbon removal plant in the world*.

The farming industry can also contribute to carbon removal by encouraging practices that *replace carbon in soil* that has been lost over the years. This has the added benefit of creating better soil. Imagine if everyone had the same soil quality as Iowa. Those soils are so good principally because they contain a lot of carbon that the plants and microbes recycle constantly, creating a rich environment for plant growth. LLNL has a large program looking at the science of soil improvement, focusing particularly on how deeply rooted plants can both

[2] http://www.netpower.com
[3] https://www.forbes.com/sites/christopherhelman/2017/02/21/revolutionary-power-plant-captures-all-its-carbon-emissions-at-no-extra-cost/#5db22e3d402d

improve yields and soil quality at the same time. We believe that deep soil carbon will be an important tool for carbon dioxide removal because: (1) soils have a huge capacity to hold carbon, (2) adding carbon improves crop production, (3) it engages farmers (who understand how to improve soil quality), and (4) it is a long-term way to keep carbon out of the atmosphere.

Another carbon removal approach leverages the mechanism that the Earth already uses to remove CO_2 from the air: *reacting it with rocks.* This natural process creates limestone, a permanent storage form for CO_2. Peter Kelemen at Columbia University has pioneered work using rocks called ultramafics, which come from deep in the earth. They react with CO_2 in the air, removing it permanently. He is examining whether these rocks, commonly found in the United States, can be forced to react more quickly by circulating water through them, forming a limestone-like rock at the surface.

Seven firms are exploring another carbon removal approach through the use of chemical processes known as *direct air capture*. Although this technology is in its infancy and additional research and development is needed to discover how expensive it will be, it is already of great interest to the corporations that want to use CO_2 in their chemical processes. If CO_2 can be captured from the air, it means these corporations would have access to an unlimited supply of feedstock. For large-scale efforts, after extraction, the CO_2 will probably need to be stored underground. Although we expect that this is fairly easy to do based on DOE's existing storage program, this is an area where demonstration and validation are important to develop confidence that this combination of new technologies (air capture and carbon storage) is a robust approach.

A small Swiss company, Climeworks,[4] has created the first commercial, for-profit project that captures CO_2 directly from the air. Climeworks captures and sells 900 tons per year of CO_2 to an organic greenhouse. This technology is mass-producible, scalable, and robust. A US corporation, Global Thermostat, is completing a demonstration capture plant in Alabama that will be much larger than the Climeworks project when it begins operation this fall.

Summary

The United States is poised to be the leader in the use of CO_2 and natural gas for new carbon products - a new carbon economy. This will improve national security as it makes us more energy self-sufficient and will create new economic opportunity. Development and demonstration of innovative technologies in which the U.S. already leads will be key to that process. Because energy and the necessary feedstocks—CO_2 and natural gas—are abundant in the central United States, we anticipate that new industries will thrive there. Both basic R&D and transfer of that research to corporate users will be important accelerators for the new carbon economy. The research and development done by the national laboratories strives to bring that vision to fruition.

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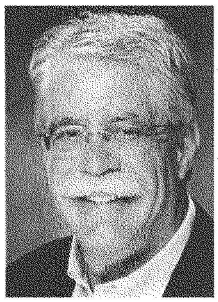
[4] http://www.climeworks.com/

Lawrence Livermore National Laboratory



ROGER D. AINES
Energy Program Chief Scientist
Global Security Principal Directorate

Ph.D. Geochemistry, California Institute of Technology
B.A. Chemistry, Carleton College

Roger Aines is the Energy Program Chief Scientist in E Program, which conducts government and private sector research in clean energy technology. He is a Senior Scientist in the Chemistry, Materials, Earth and Life Sciences Directorate at LLNL. He holds a Bachelor of Arts degree in Chemistry from Carleton College, and Doctor of Philosophy in geochemistry from the California Institute of Technology. He has been at LLNL since 1984 working on nuclear waste disposal, environmental remediation, application of stochastic methods to inversion and data fusion, management of carbon emissions including separation technology, and monitoring and verification methods for sequestration.

Roger's career has involved a close coupling of scientific research, engineering, field demonstration, and assessment of future development needs for technology. His research interests include the chemistry of natural and engineered processes, including carbon dioxide separation and water treatment. Roger's current research includes application of 3-D printing to chemical reactors and gas separations, development of catalysts for carbon dioxide capture, management of pressure in geologic sequestration through brine withdrawal and treatment, and encapsulation of carbon dioxide capture solvents. He previously led LLNL's Carbon Management Program, which takes an integrated view of the energy, climate, and environmental aspects of carbon-based fuel production and use. It supports DOE projects in sequestration technology development for capture, and carbon recycling. Roger directs the LLNL program in developing better understanding of hydraulic fracturing and tools and methods around shale gas development. He holds twenty-two patents in the areas of carbon capture, shale gas production, *in situ* degradation of organic chemicals through heating, and the mechanisms of thermally assisted remediation, and has eighty publications.

LLNL-MI-642887

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Chairman WEBER. Thank you, Dr. Aines.
Dr. Brun, you're recognized for five minutes.

TESTIMONY OF KLAUS BRUN DR. KLAUS BRUN, PROGRAM DIRECTOR, MACHINERY PROGRAM, FLUIDS & MACHINERY ENGINEERING DEPARTMENT, SOUTHWEST RESEARCH INSTITUTE

Dr. BRUN. Thank you. Good morning, Chairman Smith, Ranking Member Johnson——

Chairman WEBER. You want to turn on your mic there please, sir.

Dr. BRUN. Sorry. Good morning, Chairman Smith, Ranking Member Johnson, Chairman Weber, Ranking Member Veasey, Chairman Biggs, and Ranking Member Bonamici. My name is Klaus Brun, and I'm the Machinery Program Director at Southwest Research Institute in San Antonio, Texas. I'm honored to address you today on behalf of Southwest Research Institute.

Southwest Research Institute, headquartered in San Antonio, Texas, is one of the oldest and largest independent not-for-profit applied research and development organizations in the United States. For the last 70 years, our mission has been to work in the public's best interest and toward betterment of mankind. Southwest Research Institute currently executes approximately $550 million in contract R&D per year and employs about 2,600 staff members in Texas and throughout the United States.

Cheap and reliable electricity is the cornerstone of our economy. The supercritical carbon dioxide or SCO_2 power cycle has been a major collaborative development effort between industry, government, and research institutes to make electricity cheaper, more reliable, and also cleaner. For the last 250 years, a majority of fossil fuel power plants have been using steam and air, but technology development never stands still and we must pursue the next improvement in power plants.

The SCO_2 power cycle is not a new energy source. It is a technology that incrementally but significantly allows us to make better use of energy from conventional fossil fuels and some non-fossil energy sources. SCO_2 power cycles replace steam or air of a conventional power plant with carbon dioxide at very high pressures and high temperatures. Carbon dioxide is a common gas that is abundantly available, nontoxic, and easily handled.

Due to the high density and high heat capacity and low viscosity of SCO_2, plant efficiency gains of three to five percent are easily realized versus conventional steam plants. In industrial waste recovery, nuclear, and concentrating solar power, plant efficiency improvements of 10 to 15 percent over steam are possible. Waste heat recovery from thousands of currently underutilized energy streams in industry and oil and gas becomes technically feasible and commercially viable.

SCO_2 plants are about five to ten times smaller than conventional plants and do not require water. That drastically reduces plant capital costs, reduces footprint requirements, improves plant grid response, and allows for sitings throughout the United States.

Finally, SCO_2 technology provides a clear development path toward oxy-combustion, which is a less-expensive, higher-efficiency, and completely carbon-free emission fossil fuel power plant technology.

So why now? The thermodynamic advantages of SCO_2 power cycles have been known since the early 1950s, but at the time, the manufacturing technology, the materials, and the design tools did not exist to produce SCO_2 power cycles. Using advanced additive manufacturing, high-temperature and high-strength superalloys, and state-of-the-art computational engineering tools, all technologies have only recently become available. We can now build the complex microchannel heat exchangers and ultra-high-density energy compressors and expanders that are needed for SCO_2 power cycles. These technologies are advancing at a very rapid pace, and we expect significant further benefits and efficiency improvements to power plants in the near future.

SCO_2 power cycles are on the verge of commercialization, and the United States is clearly the leader in this technology. A mix of nearly 120 government and industry projects with approximately equal R&D funding of about $500 million from government and $500 million from industry has allowed moving technology from concept stage to functioning plants over a short period of less than eight years. Several U.S. Department of Energy offices and labs, including NETL NREL, EERE, ARPA–E, Sandia, Oak Ridge, have all constructively collaborated in this major crosscutting effort.

We are now working on an SCO_2 pilot research facility called the Supercritical Transformational Electric Power or STEP program that is designed to help industry address precompetitive development problems and demonstrate key cycle components. STEP is a $150 million DOE project led by Gas Technology Institute, Southwest Research Institute, and General Electric that aims to demonstrate 10 megawatt supercritical CO_2 power plants. The STEP facility will be located at Southwest Research Institute in Texas and is scheduled to be operational by 2020.

The STEP program and the many other industry- and government-funded SCO_2 R&D projects benefit the United States economy through the development of better power plants for cheaper, more reliable, and cleaner electricity for U.S. consumers. In my opinion, the SCO_2 power cycle collaboration and crosscutting initiatives between government, industry,, institute national labs, and academia is currently one of the most successful cooperative R&D programs in the world. Continued participation by DOE and other government agencies in these efforts will result in major benefits to the U.S. power industry, as well as U.S. energy technology leadership.

I sincerely want to thank the U.S. Government, its agencies, and its employees who continue to passionately contribute to this very important work. I'm honored to have been invited to talk about this exciting technology to the Congressional Subcommittees on Energy and the Environment. Rarely does a new technology emerge that is capable of offering so many solutions. Thank you very much, and I look forward to your questions.

[The prepared statement of Dr. Brun follows:]

Summary of Prepared Statement by Dr. Klaus Brun **August 17, 2018**
Machinery Program Director, Southwest Research Institute
For the House Science, Space & Technology Committee
Subcommittee on Energy and Environment

Cheap and reliable energy is one of the critical drivers of our economy. The sCO_2 power cycle development has been a major collaborative effort between industry, government, and research institutes to make electricity cheaper, more reliable, and also cleaner. For the last 250 years the majority of fossil-fueled power plants have been using steam and air. But technology development never stands still and we must pursue the next generation of better power plants. The sCO_2 power cycle is not a new energy source. It is a technology that incrementally, but significantly, allows us to make better use of the energy from conventional fossil and non-fossil energy sources. sCO_2 power cycles replace the steam or air of a conventional plant with carbon dioxide (CO_2) at very high pressures and temperatures. CO_2 is a common gas that is abundantly available, non-toxic, and easily handled. Due to the high density, high heat capacity and low viscosity of sCO_2, power plant efficiency gains of 3-5% are easily realized versus conventional steam plants. In industrial waste heat recovery, nuclear, and concentrating solar power, plant efficiency improvements of 10-15% over steam are possible. Waste heat recovery from thousands of currently underutilized energy streams in industry becomes technically feasible and commercially viable. sCO_2 power plants are about 5-10 times smaller than current plants which drastically reduces plant capital costs, reduces footprint requirements, and improves plant grid response. Finally, sCO_2 technology provides a line of sight development plan toward oxy-combustion: A less expensive, higher efficiency, and completely carbon-free emission fossil fuel power plant.

sCO_2 power cycles are on the verge of commercialization and the US is clearly the leader in sCO_2 power cycle technology. A mix of nearly 120 government and industry projects with approximately equal R&D funding of $500M from government and $500M from industry, has allowed moving the technology from the concept stage to functioning plants over a short period of less than 8 years. Several US Department of Energy (DOE) offices, including NETL, NREL, EERE, Nuclear, and ARPA-e, constructively collaborated in this effort. We are now working on a sCO_2 pilot research facility plant called the Supercritical Transformational Electric Power (STEP) program that is designed to help industry address pre-competitive development problems and demonstrate key cycle components. STEP is a $115M program led by the Gas Technology Institute, SwRI, and GE, and co-funded by the DOE with $80M that aims to demonstrate a 10 MW utility scale sCO_2 power plant. The STEP facility will be located at SwRI and is scheduled to be operational by 2020.

The STEP program, as well as, many industry and government funded sCO_2 power cycle technology R&D projects, benefit the US economy not simply through the development of better power plants for domestic and industrial electricity consumers, it also re-enforces the US leadership position in energy systems, power plant technology, and clean electricity. Crosscutting sCO_2 power cycle R&D will result in cheap, reliable, and clean electricity which are major drivers of the US economy.

Prepared Statement by Dr. Klaus Brun
Machinery Program Director
Southwest Research Institute
For the House Science, Space & Technology Committee
Subcommittee on Energy and Environment
August 17, 2018

Good morning Chairman Smith, Ranking Member Johnson, Chairman Weber, Ranking Member Veasey, Chairman Biggs and Ranking Member Bonamici. My name is Klaus Brun and I am the Machinery Program Director at Southwest Research Institute in San Antonio, Texas. I am honored and pleased to address you today on behalf of Southwest Research Institute.

Southwest Research Institute Background

Southwest Research Institute (SwRI), headquartered in San Antonio, Texas, is one of the oldest and largest independent, nonprofit, applied research and development (R&D) organizations in the United States. Founded in 1947 by businessman Tom Slick, Jr., SwRI provides contract research and development. We are multi-disciplinary problem solvers providing independent, premier services to government and industry clients. Since our inception more than 70 years ago our mission has been to work in the public's best interest and toward the betterment of mankind.

The institute consists of nine technical divisions that offer multidisciplinary, problem-solving services in a variety of areas in engineering and the physical sciences. More than 4,000 projects are active at the institute at any given time. These projects are funded almost equally between the government and commercial sectors. At the close of 2017, the SwRI staff numbered 2,574 employees and total revenue was more than $528 million for the fiscal year. The institute also provided more than $7 million to fund innovative research through its internally sponsored R&D program. SwRI's headquarters - with over 210 buildings - provide more than two million square feet of office and laboratory space on more than 1,250 acres in the heart of San Antonio. SwRI also has technical offices and laboratories in Boulder, Colorado; Ann Arbor, Michigan; Warner-Robins, Georgia; Ogden, Utah; Oklahoma City, Oklahoma; Rockville, Maryland; Minneapolis, Minnesota; Beijing, China; and other locations.

SwRI's research and development is very diverse and ranges from deep sea to deep space, and everything in between. We are currently active participants in several deep space missions including being the principal investigator on the Juno Jupiter mission and the New Horizons Pluto fly-by and Kuiper belt exploration missions. On the other end of the spectrum, SwRI has been involved in the design and testing of the Alvin deep sea submersibles, as well as, the Navy rescue submarine system. We are engaged in a wide range of exciting state-of-the-art research and development programs for the benefit of the US industry and government.

Supercritical Carbon Dioxide Power Cycles

Electricity consumers, both industrial and domestic, always want cheap and reliable energy. Cheap and reliable energy is one of the critical drivers of our economy. The American public cannot afford blackouts and does not want to pay high electricity bills. Over the last 40 to 50 years consumers have also started to demand that our energy is clean to produce and does not pollute our environment.

Today I would like to report on some of the exciting research and development achievements in the area of advanced electricity generation plant technology, specifically the supercritical carbon dioxide (sCO_2) power cycle. The sCO_2 power cycle development has been a major collaborative effort between industry, government, and research institutes to support the US fossil fuel power industry with advanced novel power cycle technology to make electricity cheaper, more reliable, and cleaner.

But first allow me to talk a little about the history of power plants and the importance of sCO_2 power cycles for today's power generation industry. For the last 250 years the majority of fossil-fueled power plants have been using steam and air as the working fluids in their cycle. The venerable steam engine, at least in its basic modern form, was invented by James Watt in 1781 and it, and its successor-derived products, have served us well in producing electricity for industry and consumers. We have come a long way in designing power plants and have driven efficiency up and emissions down. Even 50 years ago the average power plant efficiency was well below 25%. Today's advanced combined-cycle power plants operate near 65% efficiency with ultralow emissions of all criteria pollutants. But technology development never stands still and so now we must pursue the next generation of power plants and power storage to further improve efficiencies and reduce emissions while maintaining reliability for US electricity consumers. The sCO_2 power cycle is not a new energy source. It is a technology that incrementally, but significantly, allows us to make better use of the energy from conventional fossil and non-fossil energy sources.

Nearly 90% of all energy produced in the US comes from thermal power plants. In a thermal power plant energy is converted to electricity by heating steam or air and expanding it across a power turbine. Examples of thermal power plants include all types of coal and natural gas power plants, nuclear power plants, and even concentrating solar power plants. The sCO_2 power cycle replaces the steam or air of a conventional heat engine with carbon dioxide (CO_2) at very high pressures and temperatures. CO_2 is a common gas that is abundantly available, non-toxic, and easily handled. We consume it daily in carbonated soft drinks (and beer) and it is widely used in many industrial processes and consumer products. But CO_2 has thermodynamic properties that, when it is in a supercritical or dense phase state, make it as advantageous as a process fluid for power cycles. Several closed cycle heat engines, including the Cascade, the Allam, the Re-Compression, and the Brun thermodynamic cycles, target these physical properties of sCO_2 to make a more efficient thermal power plant.

There are significant incentives driving the development of this technology for commercial use. Due to the high density, high heat capacity and low viscosity of sCO_2, power plant efficiency gains of 3-5% are easily realized versus conventional steam plants. In some applications, such as industrial waste heat recovery, nuclear, and concentrating solar power, plant efficiency improvements of 10-15% over steam are possible. Waste heat recovery from thousands of currently underutilized energy streams in the manufacturing industry and oil & gas production and transportation becomes technically feasible and commercially viable with sCO_2 technology. Additionally, this results in the footprint of a sCO_2 power cycle being only a fraction of that of conventional plants. We expect sCO_2 power plants to be about 5-10 times smaller than current plants. This drastically reduces plant capital costs, allows for modularity of construction, and even provides the potential for mobile power plants. Also, because of its small size and low thermal mass, a sCO_2 plant can be operated dynamically and provide a fast response to electricity demand and supply changes on a grid with varying alternative - wind and solar - energy inputs. This eliminates one of the major disadvantages of many fossil power plants that can only operate in steady baseload. sCO_2 plants require no water and can easily be sited in arid regions of the US. Finally, sCO_2 technology provides a line of sight development plan toward a less expensive, higher efficiency, and completely carbon emission fossil fuel power plant. For example, using direct-fired pressurized oxy-combustion sCO_2 cycles that are currently being developed, natural gas plants with nearly complete carbon capture and efficiencies equivalent to combined-cycle plants can be achieved.

So why now? The thermodynamic advantages of sCO_2 power cycles have been known since the early nineteen-fifties. But at the time the manufacturing technology, the materials, and the design tools did not exist to produce a sCO_2 power cycle. Using advanced additive manufacturing, high-temperature and high-strength super-alloys, and advanced computational engineering design tools - technologies that have only recently become available - we can now build the complex micro-channel heat exchangers and ultra-high energy density compressors and expanders that are needed for sCO_2 power cycles. These technologies are advancing at a very rapid pace and with the US being the clear technology leader, we can expect significant further benefits and efficiency improvements to power plants in the near future.

In summary, the sCO_2 power cycle does not replace current fossil and non-fossil power plants, it just makes them more efficient and cleaner. Although steam and air cycles will continue to dominate the power generation industry in the foreseeable future, recent developments in materials, manufacturing, and design have led to the development of sCO_2 cycles as an alternative. sCO_2 plants are significantly simpler than typical steam or combined cycle plants, offer a greater power density, a higher efficiency, lower emissions, and most importantly a lower cost of electricity.

Crosscutting R&D and STEP

sCO_2 power cycles are on the verge of commercialization and the US is clearly the leader in sCO_2 power cycle technology. But other countries are trying to catch up and we need to continue to advance this technology to stay ahead. The rapid advancement of technology for the sCO_2 power cycle in the US is the result of a highly successful collaboration between industry, government, national labs, independent labs, and academia. This has been accomplished through industry and government coordinated efforts on focused R&D, cross-cutting initiatives, targeted project funding, and a tight integration of activities of national and private research laboratories, academia, and industry. A mix of nearly 120 government and industry projects with approximately equal R&D funding of $500M from government and $500M from industry, has allowed moving the technology from the concept stage to functioning machinery, subsystems, and plants over a short period of less than 8 years. In a technology area were major advances are usually measured in decades rather than years that is an incredible pace for power plant development. Clearly, this aggressive collaborative R&D approach to rapidly mature an emerging energy technology could serve as a model to advance other highly relevant energy technologies, such as energy storage or oxy-combustion, in the near future.

Several sCO_2 pilot power plants are now being built using both commercial and government funding sources for each application area including fossil fuel, concentrated solar power, and industrial waste heat recovery. Major US manufacturers, equipment suppliers and vendors, and many small startups have been able to develop their own sCO_2 products and systems, greatly benefiting directly and indirectly from government funded efforts. Government funding not only aided in risk reduction during the early concept development stages but also resulted in speeding up the product development cycle and time to market. Clearly this benefits the US public by making higher efficiency and cleaner power generation plants available to the consumer more quickly and at a lower cost.

Several US Department of Energy (DOE) offices constructively collaborated to move sCO_2 power cycle technology forward through a mix of small individual focused and large broad multi-division projects and programs. These offices included DOE NETL, NREL, EERE, Nuclear, and ARPA-e, each funding projects in their specific application area, but all coordinated to provide broad program benefits. One of the benefits is that we are now working on a sCO_2 pilot research facility plant that is designed to help industry address pre-competitive development problems jointly to continue to rapidly advance the technology and to demonstrate key advanced cycle components. This, the largest of the DOE sCO_2 power cycle crosscutting initiatives, is the Supercritical Transformational Electric Power (STEP) program. STEP is a $115M program led by the Gas Technology Institute, SwRI, and GE, and co-funded by the DOE with $80M that aims to demonstrate various configurations of a commercially relevant scale sCO_2 power plant operating up to 715 degrees Celsius firing temperature and 10 MW output power. The STEP facility will be located at SwRI and is scheduled to be operational by 2020. Beyond the primary operational and R&D program targets, STEP will serve as an open-access joint industry R&D facilities for technology developers to test and improve their sCO_2 power plant products. Basically, STEP will first validate the performance improvement predictions of the utility scale sCO_2 cycle technology and then be available to industry, government, and academia as an open reconfigurable R&D facility.

The STEP program, as well as, many industry and government funded sCO_2 power cycle technology R&D projects, benefit the US economy not simply through the development of better power plants for domestic and industrial electricity consumers, it also re-enforces the US leadership position in energy systems, power plant technology, and clean electricity. Ongoing sCO_2 activities drive cutting edge R&D projects with significant global visibility, provide hundreds of high-skills/high-wage jobs, and lead to a continuous education of world-class engineers, scientists, and researchers. Finally, crosscutting sCO_2 power cycle R&D will result in cheap, reliable, and clean electricity which are major drivers of the US economy.

Closing

SwRI is a major US not-for-profit independent R&D institute engaged in the development of advanced power generation and energy storage technologies. We have been an active leader in sCO_2 power cycle technology for the last ten years. During this time we have worked with the DOE, several national labs, universities and many industrial partners including GE, Gas Technology Institute, Aerojet Rocketdyne, Solar Turbines, and a host of others on over 30 sCO_2 related projects. In my opinion, the sCO_2 power cycle collaboration and crosscutting initiative between government, industry, institutes, national labs, and academia is currently one of the most successful cooperative R&D programs in the energy industry. Continued participation by DOE and other government agencies in the STEP program and other sCO_2 power projects will result in major benefits to the US power industry, as well as, US energy technology leadership. Rarely does a new technology emerge that is capable of offering so many solutions. The market potential for sCO_2 plants explains the rapid progress and interest in sCO_2 power.

I sincerely want to thank the US government, its various agencies, and its employees who have and continue to be actively and passionately involved in this very important work. Thank you very much! I am honored to have been invited to talk about this exciting technology to the congressional Subcommittee on Energy and Environment and I look forward to your questions.


SwRI
Overview of Supercritical Carbon Dioxide Power Plant Technology
Klaus Brun, Ph.D. – Machinery Program Director
For the House Science, Space & Technology Committee
Subcommittee on Energy and Environment
August 17, 2018
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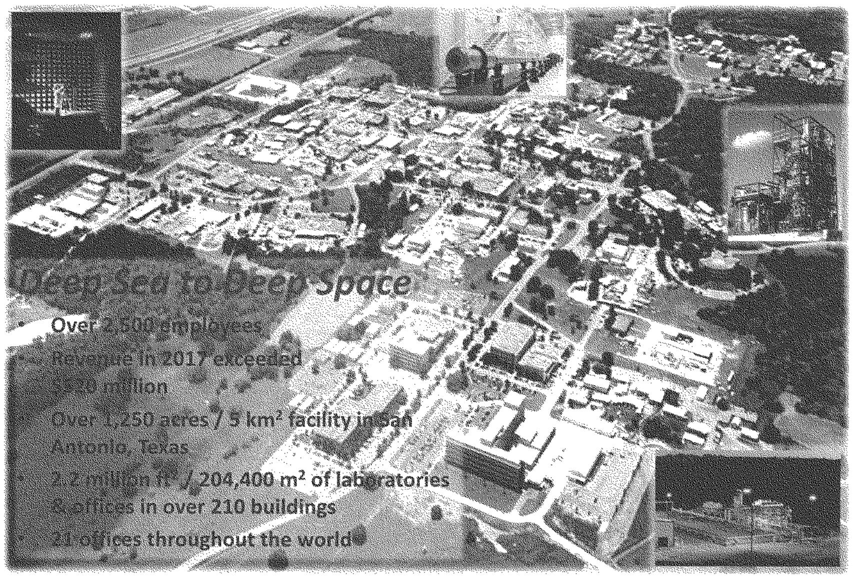


Supercritical Carbon Dioxide Power Cycles

Key Points

- Approximately 90% of all electric generation plants in the US are thermal power plants.
- The Supercritical Carbon Dioxide (sCO_2) power cycle is a novel energy conversion technology that can significantly improve the efficiency and reduce air emissions of most thermal power plants.
- Because of past US government and industry funding, the US is the clear technology leader in sCO_2 power cycles.
- SwRI has led sCO_2 power cycle R&D for over 10 years and is currently constructing a DOE co-funded 10 MW R&D pilot and demonstration plant (Supercritical Transformational Electric Power - STEP).
- Continued DOE funding of the STEP plant and other sCO_2 power cycle projects will result in major benefits to the US power industry as well as US energy technology leadership.

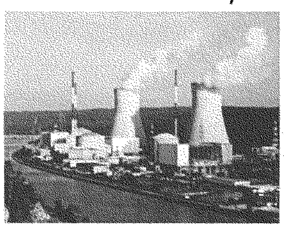
US Electric Power Generation

Cheap, Reliable and Clean Electricity

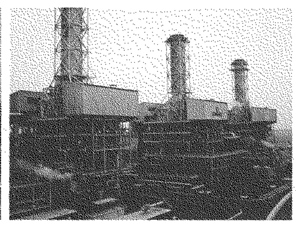
- U.S. uses diverse mix of energy
  - Fossil (coal, natural gas, oil) **67%**
  - Nuclear **20%**
  - Renewable (hydro, wind, solar, geo) **13%**

Thermal Power Plants

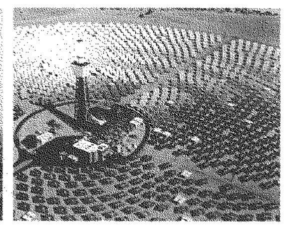
- About 90% of US generation plants are thermal power plants
- Thermal power plants convert heat to electricity
- Most are based on air or steam as the process fluid
- Efficiencies vary from 20-65%



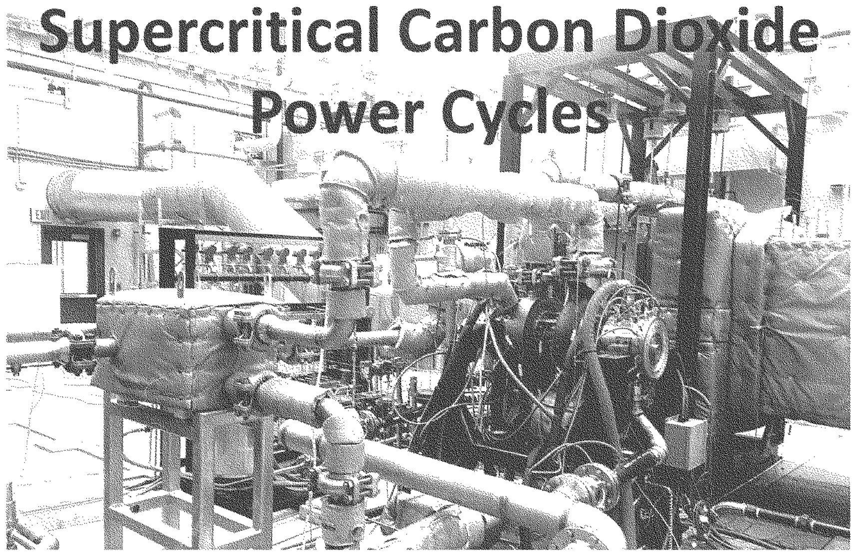
Nuclear



Fossil

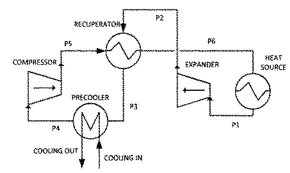


Solar

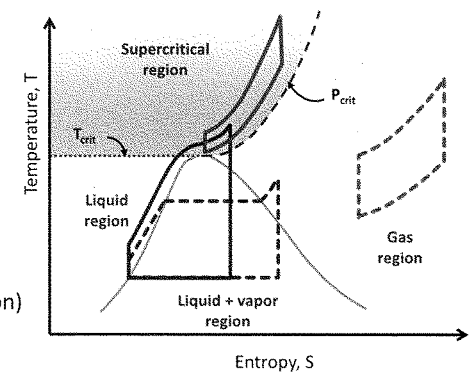

Supercritical Carbon Dioxide
Power Cycles

Supercritical Carbon Dioxide (sCO_2) Cycles

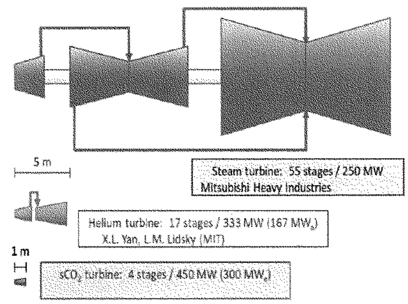
- Closed Power Plant Cycle using high pressure CO_2 as the working fluid
- Supercritical CO_2 is non-toxic, abundantly available, and is commonly used as an industrial fluid
- Supercritical fluids exhibit characteristics of both Liquids and Vapors
  - High Density
  - Low Viscosity
  - High heat capacity
- Cycle Configurations
  - Vapor Phase
  - Transcritical
  - Supercritical
- 3-5% efficiency gain over conventional steam cycles (depending on cycle and application)
- 5-10 times smaller and more compact power plants



Recuperated Closed Brayton Power Cycle

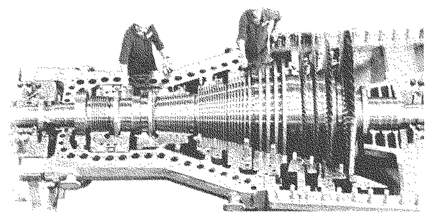


sCO_2 Plant Size

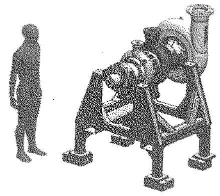


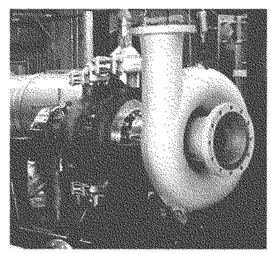
Source: Wright (2011), Adapted from Dostal (2004)

20 MW steam turbine



Predicted sCO_2 plant size 5-10 times smaller than equivalent steam cycle.
- **Lower capital costs**
- **Ease of modularity and transport**
- **Faster dynamic heat source and load response**

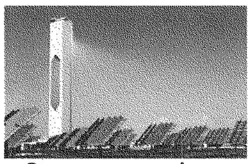




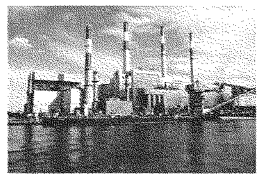
14 MW sCO_2 turbine

Applications of sCO_2 Power Cycles

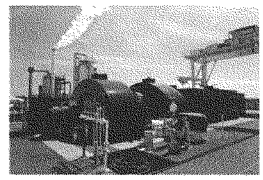
Increased Efficiency, Reduced Emissions & Lower Electricity Cost



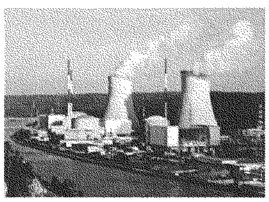
Concentrating Solar Power



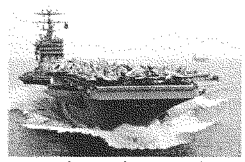
Fossil Fuel



Geothermal



Nuclear



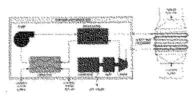
Ship-board Propulsion

Waste Heat Recovery

Benefit Across Applications

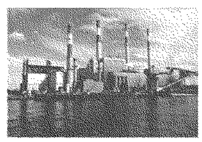
Near Term Applications

Waste Heat



- 25% Reduction in Emissions
- 12% Better Thermal Efficiency

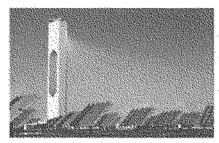
Indirect Fossil



- 7% Reduction in Emissions
- 4% Better Thermal Efficiency

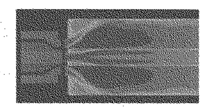
Zero Emission Technology

Concentrating Solar



- Zero emissions technology
- 16% Reduction in LCOE
- Zero cooling water use

Oxy-combustion



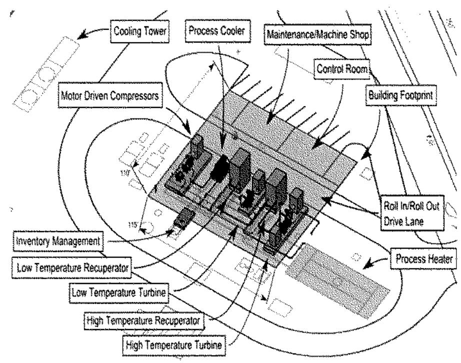
- 99% Carbon Capture with CCS

10 MW DOE STEP Pilot Plant Project

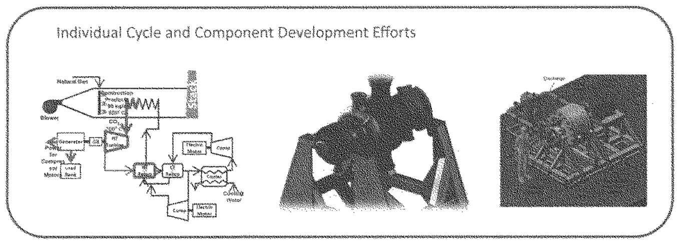
Demonstrate Utility-Scale sCO_2 Plant Function

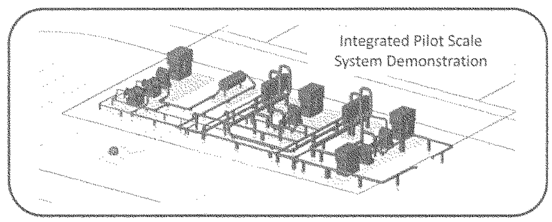
- Pilot and demonstration plant located at SwRI
- Partnering with GE and GTI
- Six year project valued $115 million ($80M DOE, $35M Industry)
- Scheduled to be operational 2020
- Testing both 550C and >700C temperature operation

STEP



Transitioning from Design to Complete System Demonstration

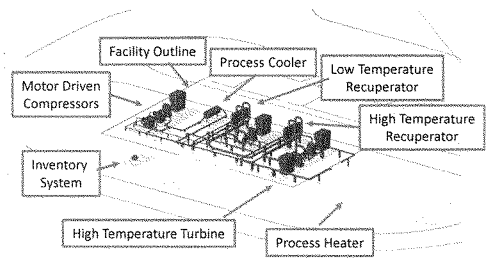




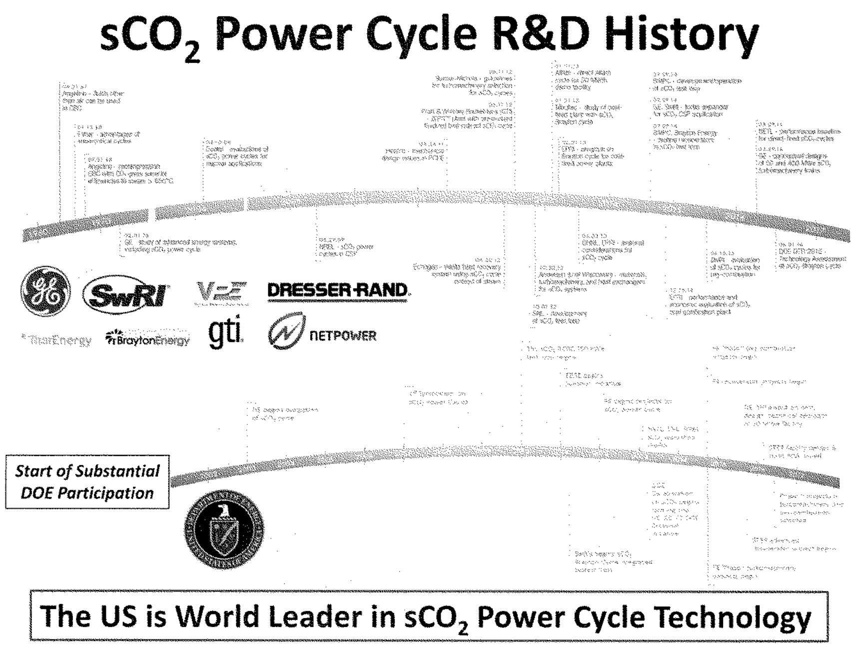
STEP is a transition from Component Development to System Demonstration

DOE STEP Project Objectives

- Demonstrate sCO_2 system operability
- Verify component performance
- Validate and Measure
  - Efficiency / emission benefits
  - Lower cost of electricity
  - sCO_2 RCBC thermodynamic cycle efficiency > 50%
- Demonstrate sCO_2 RCBC at 700°C Turbine inlet and 10 MWe net power minimum
- Reconfigurable facility to accommodate future testing



Project Site: SwRI in San Antonio, TX


sCO2 Power Cycle R&D History
Start of Substantial DOE Participation
The US is World Leader in sCO2 Power Cycle Technology

sCO_2 Power Cycle R&D Benefit to US Economy and Technology Leadership

- Re-enforces US leadership position in power plant technology, advanced energy systems, and clean power plants
- Supports ongoing commercial and government funded technology projects valued at $300M+ and boosts R&D opportunities
- Provides for cutting edge R&D projects with significant global visibility
- Provides hundreds of high skilled, high wage jobs
- Leads to continuous flow of world-class engineers, scientists, and researchers to the US
- Cooperative programs will enhance teaching and basic research at US Universities

Cheap, Reliable, and Clean Electricity:
Drivers for US Technology Leadership in Advanced Power Generation Technology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Questions Please?
Klaus Brun, Ph.D. – Machinery Program Director
klaus.brun@swri.org (210) 522-5449
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Klaus Brun – Short Bio

Dr. Brun is currently the Machinery Program Director at Southwest Research Institute where he leads an organization of more than 60 that focuses on R&D for the energy industry. He is internationally recognized for his expertise in energy systems, power generation, and turbo-machinery. He holds a B.Sc. from the University of Florida and M.Sc. and Ph.D. from the University of Virginia in Mechanical Engineering. His past experience includes positions in engineering, project management, and management at Solar Turbines, General Electric, and Alstom. He holds eight patents, authored over 350 papers, and published three textbooks on energy systems and turbomachinery. Dr. Brun is a Fellow of the ASME and won an R&D 100 award in 2007 for his Semi-Active Valve invention. He also won the ASME Industrial Gas Turbine Award in 2016 and ASME Oil & Gas Committee Best Paper/Tutorial awards in 1998, 2000, 2005, 2009, 2010, 2012, 2014, 2016, and 2017. Dr. Brun organized and chaired numerous international conferences including the International sCO2 Symposium 2016, Turbo Expo 2012, and the Oil & Gas Lecture Series 2016-2018. Dr. Brun is the past chair of the ASME-IGTI Board of Directors, the ASME Oil & Gas Applications Committee, and ASME sCO2 Power Cycle Committee. He is also a member of the API 616 Task Force, the ASME PTC-10 task force, the Asia Turbomachinery Symposiums Committee, the Fan Conference Advisory Committee, and Supercritical CO2 Symposium Advisory Committee. Dr. Brun is the past Editor of Gas Turbine News and currently the Executive Correspondent of Turbomachinery International Magazine and Associate Editor of the ASME Journal of Gas Turbines for Power.

Chairman WEBER. Thank you, Dr. Brun.
Ms. Angielski, you're now recognized for five minutes.

TESTIMONY OF MS. SHANNON ANGIELSKI, EXECUTIVE DIRECTOR, CARBON UTILIZATION RESEARCH COUNCIL

Ms. ANGIELSKI. Thank you, Mr. Chairman, and to the Members of both the Energy and Environment Subcommittees and to those Committee Members that are here today for the invitation to testify and discuss this topic with you.

CERC is an industry coalition that is focused on technology solutions for the responsible use of our U.S. fossil energy resources to support our Nation's need for secure, reliable, and affordable electricity through a balanced portfolio.

CERC serves as an industry voice to identify technology pathways that will enable our Nation to continue to enjoy the benefits of our abundant and low-cost fossil fuels in a manner that is both compatible with societal energy needs and environmental goals and objectives. Members of CERC work together to advance a common set of technology objectives that can be met through public and private-sector collaboration designed to expand technology choices for private-sector commercialization.

I want to recognize that the United States has already made significant strides in the development of advanced fossil energy resource technologies to improve the utilization of these resources. Similar to how a car, a new car today, can travel further on a single gallon of gasoline than one that was built back in the 1980s, the most advanced coal units operating today are 25 percent more efficient than the previous generation of coal units, and this is a direct result of the public-private-sector collaboration, which many of my members were involved with.

As already recognized in many of the opening statements, consumption of fossil fuels is on the rise both domestically and internationally, and this trend is projected to continue well into the future. There's growing international consensus that technologies are needed to further reduce the carbon footprint from the use of fossil fuels. As a result, more recent efforts have focused on technologies to reduce carbon dioxide emissions.

There is a first-of-a-kind carbon-capture project successfully operating on a coal-fired power plant in the United States today that is selling its carbon dioxide in a nearby oil field. Many of you from Texas may know this project, the Petra Nova project. This innovative project relied on federal financial support to launch.

And while research is advancing that will result in improved technologies, carbon capture is not yet economic for widespread application in the power sector, and further technology innovation is needed.

Later this month, CERC and the Electric Power Research Institute will release the 2018 Advanced Fossil Energy Technology Roadmap that, if implemented, projects new technologies can be available in the next decade, by 2035 time frame, that generate electricity from fossil fuels with significantly reduced carbon dioxide emissions and importantly can be cost-competitive with other sources of electricity generation.

By way of background, EPRI conducts research development and demonstration projects for the benefit of the public in the United States and internationally. As an independent, nonprofit organization for public interest energy and environmental research, they focus on electricity generation, delivery, and use in collaboration with the electricity sector, its stakeholders, and others to enhance the quality of life by making electric power safe, reliable, affordable, and environmentally responsible.

EPRI does not advocate or aim to influence policy or regulation.

This will be the fifth roadmap that CERC and EPRI have published together since 2003 and reflects the technology development needs that can support an evolving U.S. power sector that's impacted by several emerging trends driving innovation and investment decisions for new generation. Some of these trends include increased and low cost domestic supplies of natural gas, slow and in some cases declining low growth in electricity demand, as well as the need for generation to rapidly adjust to cycling load demands with increased intermittent renewables on the grid.

There are several technologies identified in the roadmap that address these trends yet enable a transformation in the way we use our fossil fuel resources. These include novel power cycles like those already discussed, the supercritical CO_2 cycles or key processes in those cycles that are designed to facilitate the capture of carbon dioxide at a lower energy penalty and cost than conventional methods. These processes are inherently more efficient, resulting in fewer emissions of both carbon dioxide and criteria emissions, less water use, and require less—fewer fossil fuels to produce electricity.

The roadmap also outlines advances in carbon-capture technologies designed to lower costs and the development and testing of these technologies at test center such as the Wyoming Integrated Test Center and the National Carbon Capture Center in Alabama.

The roadmap also identifies research on breakthrough technologies to ensure out-of-the-box thinking where fundamentally new approaches for using fossil fuels are developed and includes typical programs like those discussed by Dr. Aines. Many of the technologies identified in the roadmap are ready for pilot testing today and a few are preparing for commercial-scale demonstration.

I also want to discuss a companion analysis conducted by CERC and ClearPath Foundation with modeling provided by NERA Economic Consulting and Advanced Resources International that shows that there are significant economic benefits to the United States of the technology development outlined in the roadmap is undertaken under a wide range of scenarios.

Our analysis projects up to 87 gigawatts of market-driven carbon-capture deployment paired with enhanced oil recovery by 2040, resulting in significant increase in domestic oil production and lower cost retail electricity rates, all of which contain—contribute to substantial increases in annual GDP and are projected to result in over 800,000 new jobs through 2040. These macroeconomic benefits are described in more detail in my written testimony in a report summarizing the study that will also be released next week.

While both CERC and EPRI developed the roadmap, I just want to make sure it's understood I'm speaking only on behalf of CERC today, and we're very pleased to support the House Science, Space, and Technology Committee efforts to explore next-generation fossil power technologies and to discuss solutions that will enable our Nation to continue to responsibly benefit from the utilization of our fossil energy resources.

Thank you for the opportunity to provide you this testimony.

[The prepared statement of Ms. Angielski follows:]

Testimony of Shannon Angielski

Executive Director

Carbon Utilization Research Council (CURC)

Before the

Committee on Science, Space, and Technology

Subcommittees' on Energy and Environment

Hearing on the Future of Fossil: Energy Technologies Leading the Way

CURC Testimony:

"Advancing Fossil Energy Technology Innovation in the U.S."

Washington, D.C.

July 17, 2018

EXECUTIVE SUMMARY OF CURC TESTIMONY: KEY POINTS

CURC is an industry coalition focused on technology solutions for the responsible use of our U.S. fossil energy resources in a balanced portfolio to support our nation's need for secure, reliable and affordable electricity. CURC serves as an industry voice and advocate by identifying technology pathways that enable the nation to enjoy the benefits of abundant and low-cost fossil fuels in a manner compatible with societal energy needs and goals. CURC believes that future energy needs can be effectively met through collaborative public and private sector research to expand technology choices for private sector commercialization. Members of CURC work together to evaluate technology development needs, design appropriate research and development programs to enable those technology choices, and identify federal programs and policies needed to support this activity.

The U.S. has made significant strides in the development of advanced coal and natural gas technologies to improve the utilization of these resources. Similar to how a new car today can travel further on a single gallon of gasoline than one built in the 1980s, the most advanced coal units operating in the U.S. today are 25% more efficient than the previous generation of coal units. With further technology improvements, additional efficiency gains of similar magnitudes can be achieved for both coal and natural gas combined cycle systems.

New technologies have also resulted in significant emissions reductions since the early 1970s, even while fossil fuel use substantially increased. Additionally, technology has substantially reduced the use and discharge of water from fossil fueled power plants.

Consumption of fossil fuels is on the rise both domestically and internationally, and this trend is projected to continue well into the future due to the role fossil fuels play in providing easily accessible, reliable and low-cost energy. There is growing international consensus that technologies are needed to reduce the carbon footprint from the use of fossil fuels. As a result, more recent efforts have focused on technologies to reduce carbon dioxide emissions. There is a first-of-a-kind carbon capture project successfully operating on a coal-fired power plant in the U.S. today that is selling its carbon dioxide to enhance recovery of oil in a nearby oil field – the Petra Nova project in Texas. This innovative project relied on federal financial support to launch. While research is advancing that will result in improved technologies, carbon capture is not yet economic for widespread application in the power sector.

Later this month, CURC and the Electric Power Research Institute, Inc. (EPRI) will release the 2018 Advanced Fossil Energy Technology Roadmap that identifies the research, development and demonstration for a suite of technologies that will transform the way fossil fuels are converted to electricity. EPRI conducts research, development, and demonstration projects for the benefit of the public in the United States and internationally. As an independent, nonprofit organization for public interest energy and environmental research, they focus on electricity generation, delivery, and use in collaboration with the electricity sector, its stakeholders and others to enhance the quality of life by making electric power safe, reliable, affordable, and environmentally responsible. EPRI does not advocate or aim to influence policy or regulation. If implemented, the Roadmap identifies technologies that can be available by the 2025-2035 timeframe that generate electricity from fossil fuels with significantly reduced carbon dioxide emissions that could be cost competitive with other sources of electricity generation.

This will be the fifth Roadmap that CURC and EPRI have published since 2003. The 2018 Roadmap includes new data on recent advances in fossil fuel technologies. It also reflects the technology development needs that can support an evolving U.S. power sector impacted by several emerging trends driving innovation and investment decisions for new generation. Some of these trends include increased and low- cost domestic supplies of natural gas, slow, and in some areas of the country, declining, load growth and electricity demand, and the need for generation to rapidly adjust to cycling load demands with increased intermittent renewables on the grid.

There are several technologies identified in the Roadmap that address these issues to transform the way we use our coal and natural gas resources. These include novel fossil power cycles or key processes in such cycles that are designed to facilitate the capture of CO_2 at a lower energy penalty and cost than conventional methods. These processes are inherently more efficient, resulting in fewer emissions of both CO_2 and criteria pollutants, and require fewer fossil fuels to be used to produce electricity. There is specific research identified in the Roadmap that is also necessary to support these new cycles, including advancements in turbine technologies, and high-temperature materials necessary to achieve higher efficiencies. In addition, the Roadmap outlines advances in carbon capture technologies designed to lower costs, and the development and testing of these technologies at test centers such as the Wyoming Integrated Test Center and the National Carbon Capture Center in Alabama. Research on breakthrough technologies is also needed to ensure "out-of-the-box" thinking or fundamentally new approaches to solving fossil fuel's challenges are developed.

Many of the technologies identified in the Roadmap are readying for pilot testing now and a few are preparing for commercial-scale demonstration. It is critical that federal policies support not only the R&D outlined in the Roadmap, but also the piloting and demonstrating of these innovative, first of a kind technologies.

Companion analysis conducted by CURC and ClearPath, with modeling provided by NERA Economic Consulting and Advanced Resources International, shows that there are significant economic benefits to the U.S. if the technology development outlined in the Roadmap is undertaken under a wide range of scenarios. Our analysis projects up to 87 GW of market-driven carbon capture deployment paired with enhanced oil recovery by 2040, resulting in a significant increase in domestic oil production and lower cost retail electricity rates, all of which contribute to substantial increases in annual GDP as well as over 800,000 new jobs through 2040. These macroeconomic benefits are described in more detail in my written testimony.

While both CURC and EPRI developed the Roadmap, I am speaking only on behalf of CURC, and CURC is pleased to support the House Science, Space and Technology Committee efforts to explore next generation fossil power technologies and discuss technology solutions that will enable our nation to continue to responsibly benefit from the utilization of our fossil energy resources.

Thank you for the opportunity to provide this testimony.

INTRODUCTION AND BACKGROUND

CURC is an industry coalition focused on technology solutions for the responsible use of our fossil energy resources in a balanced portfolio to support our nation's need for secure, reliable and affordable energy.[1] CURC serves as an industry voice and advocate by identifying technology pathways that enable the nation to enjoy the benefits of abundant and low-cost fossil fuels in a manner compatible with societal energy needs and goals. CURC believes that future energy needs can be effectively met through collaborative public and private sector research to expand technology choices for private sector commercialization. Members of CURC work together to evaluate technology development needs, design appropriate research, development and demonstration (RD&D) programs to enable those technology choices, and identify federal programs and policies needed to support this activity.

The U.S. has made significant strides in the development of advanced coal and natural gas technologies to improve the utilization of these resources. Similar to how a new car today can travel further on a single gallon of gasoline than one built in the 1980s, the most advanced coal units operating in the U.S. today can produce 20% more electricity than the previous generation of coal units with the same amount of fuel. With further technology improvements, additional efficiency gains of similar magnitudes can be achieved for both coal and natural gas combined cycle systems.

New technologies have also resulted in significant emissions reductions since the early 1970s, even while coal use substantially increased. Additionally, technology has substantially reduced the use and discharge of water from fossil fueled power plants.

Our nation's coal and fossil fuels play a significant role in the global and domestic energy economy. Domestically, coal and natural gas comprised 43% of total U.S. energy consumption and 47% of net electricity generation in 2017. The U.S. Energy Information Administration (EIA) estimates that coal and natural gas will provide 56% of total U.S. net electricity generation in 2040 (see Figures 1 and 2). Globally, consumption of coal and natural gas are projected to provide 45% of our energy consumption in 2030 and will grow to nearly 50% of global consumption by 2040 (see Figure 1).

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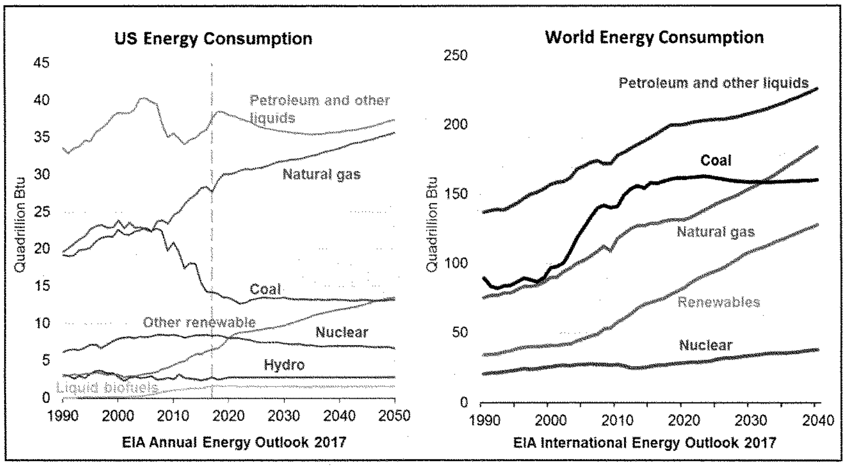
[1] CURC's members include coal producers, electric utilities that rely upon coal and natural gas for electricity production, equipment manufacturers and technology innovators, national associations that represent the power generating industry, and state, university and technology research organizations. See Appendix for a list of CURC members, as well as our website: http://curc.net/curc-members

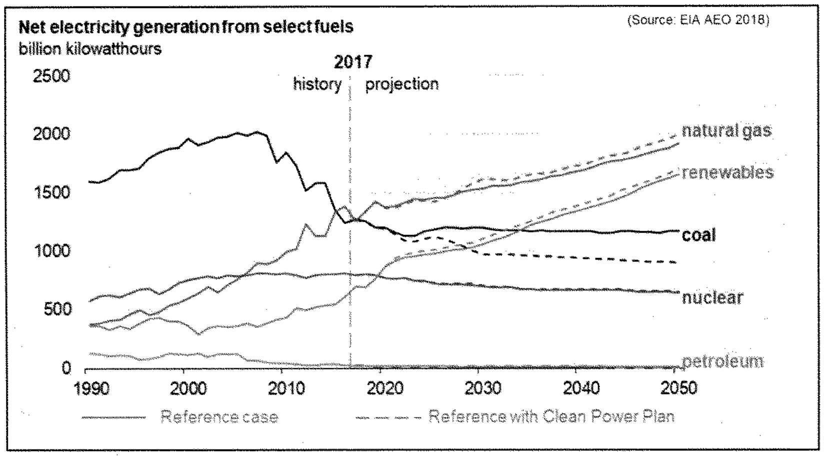
Figure 1 - U.S. and World Energy Consumption[2]



Technologies to address the growing use of fossil fuels in the power sector must be developed and deployed to reduce the carbon footprint from the use of fossil fuels. Models show the need for technologies that significantly reduce carbon dioxide (CO_2) emissions profiles to meet global climate targets (see Figure 3). Yet cost-effective, commercially-tested technologies to enable a transformational change in the conversion of fossil fuels to electricity with carbon capture, utilization and storage (CCUS) are not available today.

[2] EIA Annual Energy Outlook 2017, EIA International Energy Outlook 2017.

Figure 2 - U.S. Electricity Generation Projections[3]



CURC, in collaboration with the Electric Power Research Institute, Inc. (EPRI), will next week release an *Advanced Fossil Energy Technology Roadmap* ("Roadmap"). EPRI conducts RD&D projects for the benefit of the public in the United States and internationally. As an independent, nonprofit organization for public interest energy and environmental research, they focus on electricity generation, delivery and use in collaboration with the electricity sector, its stakeholders and others to enhance the quality of life by making electric power safe, reliable, affordable and environmentally responsible. EPRI does not advocate or aim to influence policy or regulation. .

The Roadmap outlines several RD&D pathways for both new and existing coal and natural gas technologies that will result in a suite of low-carbon, fossil-fuel platforms capable of being cost competitive with other forms of electricity generation in future electricity markets. The Roadmap reflects the technology development needs that can support an evolving U.S. power sector impacted by multiple trends driving innovation and investment decisions for new generation. The Roadmap also takes into consideration that technology development must ensure a minimal environmental footprint from the use of fossil fuels, including reduced water consumption and utilization or conversion of byproducts including CO_2. The comments provided in my testimony today are based on the findings of the *2018 CURC-EPRI Advanced Fossil Energy Technology Roadmap* and reflect only CURC's comments regarding the Roadmap.[4]

SUMMARY OF CURC-EPRI ROADMAP FINDINGS

The Roadmap emphasizes development of technologies that can result in cost-competitive and low or near-zero CO_2 emissions generation technologies, in addition to other technology areas that mitigate the environmental footprint of using fossil fuels. The 2018 Roadmap includes new data on recent advances in fossil fuel technologies and identifies the research, development and demonstration (RD&D) for a suite of technologies that will transform the way fossil fuels are converted to electricity. Our analysis determined that many technologies are applicable to

[3] U.S. EIA Annual Energy Outlook 2018.
[4] CURC-EPRI Advanced Fossil Energy Technology Roadmap, 2018.

both coal- and natural gas-fired power generation, through which public-private sector funding and support can be leveraged to develop technologies for applications using both resources.

The Roadmap identifies a suite of transformational technologies to generate a new learning curve or use new approaches for power generation and/or carbon capture that enable substantial breakthrough performance improvements and cost reductions. These encompass a broad range of technology improvements, including thermodynamic improvements in energy conversion and heat transfer, turbines and CO_2 capture systems that all drive cost reductions as well as reduce the consumption of energy needed to operate the CO_2 capture system. These technologies will result in a step change improvement in performance, efficiency, flexibility, environmental performance and cost from the use of fossil fuels (see Table 1 in Appendix). For each of these technologies, the Roadmap identifies the cost and performance targets and the technology development necessary to bring each technology to commercialization to achieve those targets. The development needs and funding requirements for each technology are rolled up into an overall technology development timeline and funding schedule. The Roadmap identifies a level of RD&D to ensure timely solutions are developed and pursued through aggressive public-private partnerships.

The transformational technologies examined in the Roadmap include pressurized oxy-combustion (P-Oxy), chemical looping combustion (CLC) and supercritical carbon dioxide (sCO_2) cycles, which would replace steam with sCO_2 as the working fluid – including both the direct- and indirect-fired sCO_2 cycles. New turbines and other components to support the higher temperatures and pressures of these systems, particularly the sCO_2 cycles, were also considered. Each of these new technologies is projected to be extremely efficient, be more compact and lower cost, and are designed to yield lower costs and energy penalties associated with the capture of CO_2.

The Roadmap also evaluates the cross-cutting RD&D needed for a range of technologies applicable to both coal- and natural gas-firing units. Cross-cutting technologies include high-efficiency materials development, carbon capture, carbon utilization and storage, turbines, and a program that evaluates other cross-cutting research such as water management, sensors and controls.

Advanced Ultra-supercritical (A-USC) materials enable Rankine cycles with steam temperatures of 700°C or higher and are also needed for the transformational high-temperature and pressure power cycles. The Roadmap identifies the RD&D needs for A-USC materials development, the testing of A-USC materials and components under real operating conditions and demonstrating supply-chain fabrication capability for key full-scale A-USC components.

The Roadmap also considers carbon capture development paths for solvents, sorbents and membranes for post-combustion capture and chemical and physical absorbents and membranes for pre-combustion capture systems, which are projected to have much lower energy penalties, yielding higher efficiencies and lower costs. Carbon capture technologies in the Roadmap address pathways for both coal-fired power plants and NGCC plants. CURC recommends that any federal program for carbon capture supports both coal and natural gas technology pathways.

CO_2 utilization and storage is an important effort to evaluate geologic CO_2 storage reservoirs, necessary to ensure there will be readily accessible storage facilities for CO_2 produced from the advanced power systems under development. The Roadmap includes a program to advance technologies in this area that will help grow our economy and increase our energy independence through the utilization of CO_2, and for which low-cost, industrial sources of CO_2 will be sought for enhanced oil and gas recovery. There are also niche opportunities to convert CO_2 into other products, including chemicals, fuels and cement that should be pursued with federal RD&D support.

Lastly, the Roadmap identifies a program for "breakthrough" technology advances that reflect "out-of-the-box" thinking for fundamentally new approaches to solving fossil fuel's challenges. Examples of breakthrough technologies include the substitution of bio-systems for current chemical processes and CO_2 sorbents based on new human-made compounds. Support for these kinds of activities is consistent with RD&D supported through the DOE's Advanced Research Projects Agency-Energy program or the fundamental research conducted in the applied energy programs at DOE.

DEVELOPMENT EFFORTS IDENTIFIED IN THE ROADMAP

Early in the technology-development cycle, the technical risks for new energy technologies are incredibly high, particularly when moving an idea from concept designed on paper and turning that concept into an actual working technology. Not only are technologies at this stage a long way from commercialization, each phase of development carries significant technical risk. Since energy technologies are capital intensive, costs increase with each scale-up in development. Each of these factors makes it difficult to attract the private sector investment required to finance technologies at an earlier stage and even mid-stages of development, making federal support for scale-up stages of technology critical to attracting the necessary private sector cost-share. Given the timing of commercialization to achieve a return on investment for energy sector technologies, federal support at all of these stages is critical to successfully commercialize such technologies.

The ultimate value of a new energy technology is generally not realized until several commercial-scale replications have occurred, which can take 20 years from concept to commercialization for large, capital-intensive energy systems. The good news is that the higher costs associated with new energy technologies can be reduced through learning by doing, which means the second-of–a-kind replication will cost less than the first.

New commercial-scale technologies cannot leap from a conceptual stage to commercial deployment in a single step. The Roadmap includes support of large-scale pilots for testing new technologies under real operating conditions at a scale beyond laboratory- and bench-scale, and before testing technologies in a commercial-scale demonstration. Large-scale pilot projects are mostly still early in the technology development timeline; the remaining time to commercialization and the risk that the process might not work at scale makes both commercial and internal financing often more challenging than either basic research or full-scale commercial-scale demonstrations. The success of technologies at the pilot scale can help to understand and overcome the risks inherent in early phase technology development and, if successful, encourage industry to make investments to advance the technologies to commercial implementation.

PROJECTED BENEFITS OF ROADMAP

Successful implementation of the Roadmap can result in significant environmental, economic and energy security benefits for the U.S., including:

1. Further reduction of water use and air pollutants, including nitrogen oxides (NOx), sulfur dioxide (SO_2), mercury (Hg) and particulate matter (PM) (see Figures 3 and 4 below);
2. Reduction of CO_2 emissions;
3. Production and preservation of affordable electricity essential for U.S. competitiveness through a diverse generation technology portfolio;
4. Enabling U.S. engineering and manufacturing expertise to grow, resulting in a robust U.S. supply chain and positioning the U.S. to be even more of a global leader in innovative fossil-fuel technologies;

5. Significant growth in gross domestic product (GDP) and jobs due to the macroeconomic impacts of increased domestic oil production and reductions in the cost of electricity (COE);
6. Improved energy security by:
    a. Generating affordable power for electricity consumers including increased industrial and advanced manufacturing customers;
    b. Improving the operational flexibility of existing and future generating plants to ensure continued electricity grid reliability and stability; and
    c. Using captured CO_2 as a commodity to recover crude oil, thereby increasing domestic oil production.

Figure 3 - Emissions Reductions from New Coal Plants Projected in CURC-EPRI Roadmap

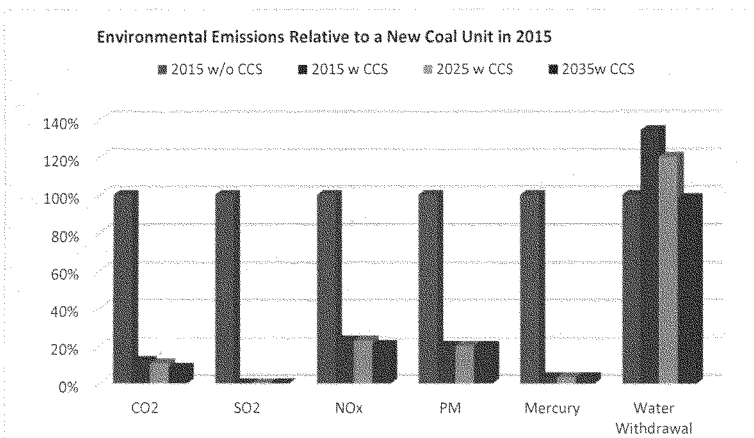
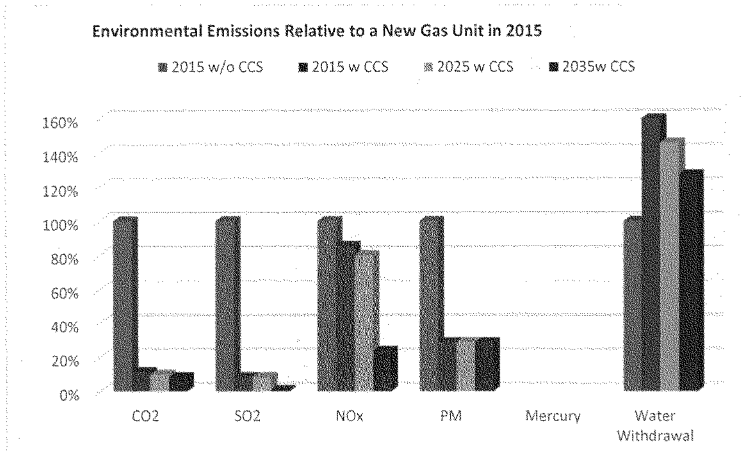


Figure 4 - Emissions Reductions from a new Gas Unit Projected in the CURC-EPRI Roadmap



If the RD&D outlined in the Roadmap is undertaken, the following COE projections are estimated with improved technology:

New Coal Unit with 90% Carbon Capture:

- 2030 – 20% reduction in COE compared to a new unit built with CCS in 2015
- 2040 – 40% reduction in COE compared to a new unit built with CCS in 2015

These projected cost improvements meet the cost reduction goals set by DOE in its 2013 Carbon Capture Technology Program plan for coal-based CCS systems.

New Natural Gas Unit with 90% Carbon Capture:

- 2030 – 15% reduction in COE compared to a new unit built with CCS in 2015
- 2040 – 30% reduction in COE compared to a new unit built with CCS in 2015

CURC and ClearPath Foundation will publish next week the results of a study that projects the macroeconomic benefits to the U.S. of new, lower-cost fossil energy technologies with CCUS as projected by the Roadmap.[5] The study estimates that if an aggressive RD&D program is implemented that achieves the above cost targets, market-driven deployment of 62 to 87 GW of power-sector projects with installed carbon capture technologies for enhanced oil recovery can be enabled by 2040.

Under an aggressive RD&D scenario that achieves the CURC-EPRI cost targets, the macroeconomic impacts of CO_2 captured from the power sector for use in enhanced oil recovery (EOR) can:

[5] CURC and ClearPath Foundation, "Making Carbon a Commodity: the Potential of Carbon Capture RD&D," July 2018.

- Contribute up to 925 million barrels of annual domestic oil production
- Increase coal production for power by as much as 40% between 2020 and 2040
- Add 270,000 to 780,000 new jobs relating to increased oil production
- Result in a $70 to $190 billion increase in annual GDP by 2040.

The study also estimates that lower-cost electricity generated from low-cost carbon capture-enabled systems also yield significant macroeconomic benefits. Aggressive RD&D is estimated to reduce the retail COE up to 2.0% by 2040, which would increase annual GDP by $30 to $55 billion and create an additional 210,000 to 380,000 jobs.

CONGRESSIONAL EFFORTS IN SUPPORT OF FOSSIL ENERGY RD&D

Since the 2015 Roadmap, there has been growing support for policies that favor CCUS and the technology recommendations that achieve the Roadmap objectives, including a program for large-scale pilots. In FY 2017, Congress appropriated $50 million for the U.S. Department of Energy (DOE) to undertake a new, transformational coal pilot program. The DOE program has solicited projects for both processes and components, along with post-combustion carbon capture, aimed at enabling step-change improvements in coal-powered system efficiency, COE and carbon capture performance.[6] The program will be carried out in three phases, with the first phase nearing completion with nine projects having been selected to develop initial design concepts.[7] The intent of the program solicitation is to ultimately design, construct and operate two large-scale pilots with these transformational attributes. Congress appropriated an additional $35 million in FY 2018 to support the total $100 million program.

In the last Congress, legislation that originated in this Committee through the America COMPETES Act (H.R. 1806) and in the Senate the Energy Policy Modernization Act (S. 2012), included provisions reflecting the 2015 Coal Technology Roadmap programs. While the House and Senate each passed their version of comprehensive energy bills, the Conference Committee could not agree on a final package. Despite this, the Fossil Energy RD&D provisions of both bills focused on programs aimed at improving the efficiency, effectiveness and environmental performance of fossil energy use consistent with CURC's priorities and the Roadmap programs.

The Senate reintroduced their comprehensive bill in this Congress, S. 1460, which includes the Fossil Energy RD&D provisions from the earlier bill, S. 2012. The "FUEL Act" (S. 2803) was also introduced in May 2018, which amends the S. 2012 RD&D provisions to reflect the new CURC-EPRI Roadmap programs that will be published in our 2018 report. In the House, H.R. 5745 has been introduced, which would likewise authorize several programs that align with the direction of the 2018 CURC-EPRI Roadmap technology programs.

While both CURC and EPRI developed the Roadmap, I am speaking only on behalf of CURC, and CURC is pleased to support legislation that will advance the Roadmap technology objectives. CURC looks forward to working with the House Science, Space and Technology Committee Members as you continue to explore next generation fossil power technologies and discuss technology solutions that will enable our nation to continue to responsibly benefit from the utilization of our fossil energy resources.

Thank you for the opportunity to provide this testimony.

[6] https://www.energy.gov/articles/department-energy-announces-50-million-large-scale-pilot-fossil-fuel-projects

[7] https://www.energy.gov/articles/department-energy-invest-65-million-large-scale-pilot-fossil-fuel-projects

APPENDIX

Table 1 - Technology Programs Supported in the CURC-EPRI Roadmap

Transformational Advanced Energy Systems		
Pressurized Oxy-Combustion (P-Oxy)	Coal and Natural Gas	Oxy-combustion power plants remove nitrogen from air cryogenically and perform the combustion of fossil fuels with oxygen and recycled flue gas to produce a stream largely comprised of CO_2 and water, greatly simplifying carbon capture. P-Oxy operates at elevated pressure, improving efficiency and allowing smaller components that combine to potentially reduce costs.
Chemical Looping Combustion (CLC)	Coal and Natural Gas	CLC is a form of oxy-combustion in which oxygen from air is separated using a metal oxide or limestone oxygen carrier, eliminating the need for cryogenic air separation and its significant energy penalty, while maintaining the relatively easy carbon capture provided by oxy-combustion.
Direct-Fired Supercritical CO_2 (sCO_2) Cycles	Coal and Natural Gas	A form of oxy-combustion, direct-fired sCO_2 cycles burn natural gas or syngas (provided by coal gasification) in a high-pressure oxy-combustor, producing very high-temperature CO_2 and water that drive a sCO_2 turbine to make power. Water and CO_2 (at pipeline pressure) are then removed downstream to conserve mass, producing a very-high-efficiency, potentially low-cost carbon capture system.
Indirect-Fired sCO_2 Cycles	Coal and Natural Gas	Replace steam-Rankine cycles with sCO_2 cycles which, due to the superior thermodynamic qualities of CO_2, have higher efficiency and utilize more compact turbomachinery. Can be used on any cycle that currently uses a steam-Rankine cycle, including solar thermal, geothermal, nuclear, biomass and any type of fossil fuel. The process results in higher efficiency and can be coupled with a low-cost carbon capture system.
Gasification	Coal	Coal can be gasified in either an air- or oxygen-blown gasifier to produce synthetic gas (syngas) that can be used in an efficient integrated gasification combined cycle system. Pre-combustion carbon capture can be added. New, highly efficient, compact gasifiers can be used in poly-generation plants that combine electricity generation with co-production of transportation fuels, fertilizer and/or other chemicals to improve the overall economics.
Compact Hydrogen Generator	Natural Gas	New, highly efficient method for producing hydrogen (alternative to steam-methane reforming).
Cross-Cutting Technologies		
A-USC Materials	Coal and Natural Gas	A-USC materials are needed to allow working fluid temperatures up to 760°C to support highly efficient combustion and heat exchange systems for both steam-Rankine and sCO_2 power systems and other high-temperature technologies. Can be applicable to both new and existing plants.
Turbines	Coal and Natural Gas	RD&D and testing of steam turbines, combustion turbines, and sCO_2 turbines and pressure-gain combustion, all in an effort to improve efficiency, reliability and

Transformational Advanced Energy Systems		
		flexibility and support power systems evaluated in the Roadmap.
CO_2 Capture	Coal and Natural Gas	Advances in solvents, sorbents and membranes for both pre- and post-combustion carbon capture focused on lowering energy requirements and overall cost of capture. Technologies will need to be adjusted to handle the differences between coal and natural gas flue gas, which include different CO_2 concentrations and trace species.
CO_2 Storage	Coal and Natural gas	Saline reservoirs, enhanced oil and gas recovery, and other geologies are being explored for storing CO_2 both onshore and offshore. RD&D as well as large-scale CO_2 storage and regional infrastructure strategies related both to storage and transportation in the U.S. are needed
Existing Plants	Coal and Natural Gas	RD&D to support flexibility and reliability of operations of existing plants
Cross-Cutting	Coal and Natural Gas	RD&D on technologies that support all Roadmap areas, including: • Advanced manufacturing • Breakthrough technologies • Sensors and controls • Water management

BIOGRAPHY

Shannon Angielski

Principal, Governmental Affairs, Van Ness Feldman

Carbon Utilization Research Council

Shannon Angielski is a principal at Van Ness Feldman LLP, a Washington D.C. based law firm that specializes in energy, environment and natural resource policy and law, and serves as the Executive Director of the Carbon Utilization Research Council (CURC), an organization of utilities, producers, equipment suppliers, universities and institutions of higher learning, and state based entities interested and involved in the use of fossil fuel resources and the development of fossil fuel-based technologies. CURC is a leading advocate for advancing public-private partnerships designed to support advanced coal and natural gas technology research, development and deployment programs, and is responsible for the design and implementation of several federal policies necessary to ensure the availability of cost-effective technology solutions for fossil fuel based generation.

Shannon earned her M.S. in Environmental Science and Public Policy from Johns Hopkins University in 2000 and her B.A. in Political Science and International Affairs from the University of New Hampshire in 1994. She is a member of the National Coal Council, the American League of Lobbyists and the Environmental Law Institute, and serves on the board of the Washington Coal Club.

Carbon Utilization Research Council (CURC) Members

Coal Producers
Arch Coal, Inc.
Cloud Peak Energy Resources LLC *
Lignite Energy Council
Peabody Energy*

Equipment Suppliers
B&W Power Generation Group, Inc.
Caterpillar Global Mining
General Electric*
Mitsubishi Heavy Industries America, Inc. (MHIA)

Labor Unions
United Mine Workers of America
International Brotherhood of Boilermakers
International Brotherhood of Electrical Workers

NGOs
ClearPath Action
EnergyBlue Project

Technology Developers
Jupiter Oxy Corp
NET Power

1

Research Organizations
Battelle
Electric Power Research Institute (EPRI)
Gas Technology Institute
University of North Dakota Energy & Environmental Research Center

State Organizations
Energy Industries of Ohio
Greater Pittsburgh Chamber of Commerce
Illinois Coal Association
Kentucky Energy & Environment Cabinet
Southern States Energy Board
West Virginia Coal Association
Wyoming Infrastructure Authority

Trade Associations
American Coal Council
American Coalition for Clean Coal Electricity (ACCCE)
Edison Electric Institute (EEI)
National Rural Electric Cooperative Association (NRECA)

Universities
Lehigh University
Ohio State University
Pennsylvania State University
Southern Illinois University
University of Illinois/PRI
University of Kentucky/CAER
University of Wyoming
West Virginia University

Utilities
American Electric Power (AEP)
Basin Electric Power Cooperative*
Duke Energy Services
LG & E and KU Services Company
Southern Company*
Tri-State Generation & Transmission Association

Companies in orange indicate Steering Committee Members

*CURC Leadership Council

Chairman WEBER. Thank you, ma'am.
Mr. Begger, you're recognized for five minutes.

TESTIMONY OF MR. JASON BEGGER, EXECUTIVE DIRECTOR, WYOMING INFRASTRUCTURE AUTHORITY

Mr. BEGGER. All right. Mr. Chairman, Members of the Subcommittee, I appreciate the opportunity to speak to you today about our carbon technology efforts in Wyoming. My name's Jason Begger, and I'm the Executive Director of the Wyoming Infrastructure Authority. The WIA is a state instrumentality tasked with promoting and assisting the development of energy infrastructure.

Currently, our largest project is the Wyoming Integrated Test Center, the ITC, which is a private-public partnership between the State of Wyoming, Basin Electric Power Cooperative, Tri-State Generation and Transmission Association, and the National Rural Electric Cooperatives Association. We have also received various in-kind contributions from Black Hills Energy and Rocky Mountain Power. I cannot stress enough the importance of this private-sector partnership because we shouldn't be focusing on projects and technologies that industry won't adopt and commercialize.

While we believe there's an important role for the federal government to play in advancing technology and we would welcome a partnership, not one cent of federal dollars has been utilized at this facility.

The ITC is a post-combustion flue-gas research facility located at Basin Electric's Dry Fork power station near Gillette, Wyoming. It is the largest facility of its kind in the United States, delivering up to 18-megawatt-equivalent 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 about .4 megawatt equivalent and a large test bay that can host two demonstration projects with a cumulative total of 18 megawatts.

Last month, we formalized a two-year partnership agreement with the National Carbon Capture Center in Alabama, which manages much of the Department of Energy's carbon-capture efforts. In Wyoming, we don't want to duplicate the work already being done; we want to complement the other test centers by providing a place to scale up current research. Our goal is to test technologies to both capture and manage the carbon.

One of the most exciting partnerships we've developed is with the XPRIZE Foundation. 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. 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 was created in the mid-'90s. The NRG COSIA Carbon XPRIZE will award $20 million in prizes to teams that are best able to convert CO_2 into other valuable products.

Currently, there are ten teams from six countries working in the final round to create things such as carbon nanotubes, methanol, building materials, fish food, and plastics. The five finalists testing at the ITC are working to Converse CO_2 from a coal-fired power plant, and there are five teams testing their technologies at a natural gas facility in Alberta, Canada. In April, Wyoming and the Japan Coal Energy Center announced a multiyear project, which will test Kawasaki Heavy Industries' solid sorbent carbon-capture technology.

Stable, predictable, and adequate funding is necessary to commercialize these technologies. H.R. 5745 is a great start, but Congress may need to look at establishing other programs to scale up the most promising technologies. Finding funding to support a new program is always a challenge. However, the coal mined in the United States provides an opportunity. The majority of the coal mined in the United States is owned by the Federal Government and leased to companies. These companies pay a variety of taxes, including federal mineral royalties, bonus bids, abandoned mine lands fees, and gross proceeds taxes. Every year, the mineral royalties and bonus bids bring in about $500 million. With a ten-year authorization, half of that funding could provide about $2.5 billion to fund carbon management research.

Technology is apolitical, and the United States can make its best and greatest impact by investing in technology development that could 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 U.N. Intergovernmental Panel on Climate Change to DOE acknowledges that 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.

[The prepared statement of Mr. Begger follows:]

Wyoming INFRASTRUCTURE AUTHORITY

Written Testimony Submitted to the United States House of Representatives Committee on Science Subcommittee on Energy

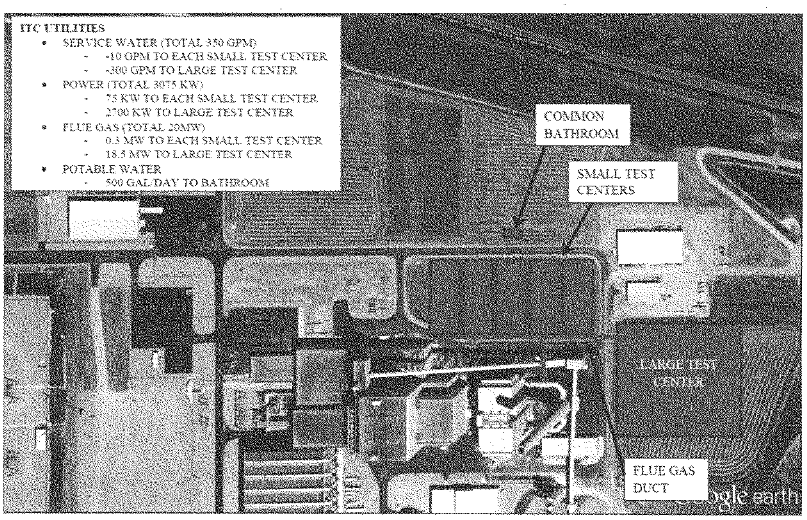
Developing and Deploying Advanced Clean Energy Technologies

Submitted by Jason Begger, Executive Director, Wyoming Infrastructure Authority, July 17, 2018

The Wyoming Infrastructure Authority 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 (ITC), which was officially dedicated in May 2018. The ITC 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 20 MWe worth of scrubbed flue gas to researchers testing Carbon Capture, Utilization, and Storage (CCUS) technologies. The power plant will provide flue gas to six small research bays, each capable of hosting tests up to 0.4 MWe and a large test bay that can host two demonstration projects with a cumulative total of 18 MWe.



Wyoming INFRASTRUCTURE AUTHORITY

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 technological solutions to ensure the long-term economic viability of Wyoming's fossil energy resources. Reviewing where Wyoming could make the most impact in carbon management technology development, it was discovered that there are no testing facilities in the United States that could host pilot scale project greater than a few megawatts. In fact, the Department of Energy (DOE) has funded testing projects at Technology Centre Mongstad (TCM) in Norway due to the lack of a suitable site in the U.S.

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National Carbon Capture Center (NCCC) is a DOE funded facility that is operated by Southern Company at one of their coal-fueled power plants near Wilsonville, AL. They are the preeminent facility in the United States on carbon management, but the largest test they can host is about 1.5 MWe. Most utilities say they need to see a successful test at greater than 10 MWe before having the comfort to construct a commercial facility.

Large pilot testing does occur in the United States, but it is very difficult for researchers to obtain permission to test at an operating power plant. The ITC aims to eliminate this hurdle by having the offtake equipment and relationship with the utility in place to become a "plug and play" facility for CCUS technologies. The ITC formalized a two-year cooperative agreement with NCCC to tap into their expertise and gain access to the researchers who have been successful at smaller scales and are ready to scale up their projects.

The ITC is just one of a number of Wyoming programs aimed at commercializing next generation coal technologies. Wyoming has invested millions over the past 15 years to conduct the basic and applied research necessary to understand all of the various components of a large-scale CCUS project.

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 Center for Economic Geology Research 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's Technical Advisory Committee. This committee is comprised of representatives from major utilities who are involved in the technology evaluation processes for their various companies and they provide this expertise to reviewing applications for technologies wishing to test at the ITC. If a utility does not see a particular technology as something they would employ, it is not given priority.

Carbon management is a two-phase process. First, the CO2 must be economically and efficiently captured from the source. In the case of a coal-fueled power plant, about 12% of the exhaust gas is CO2. In a plant such as Dry Fork Station, which utilizes state of the art scrubbers, low NOX burners, bag houses and activated carbon to remove the sulfur dioxide, nitrous oxides, particulates and mercury, the remainder of the flue gas is largely water vapor.

The second phase is utilizing the CO2 in some capacity. Generally, the CO2 is compressed into a supercritical liquid that can be more easily transported by pipeline or truck. The largest consumer of CO2 is currently EOR. It can also be injected into suitable geologic formations for permanent disposal or converted into some other product.

There are a number of different capture technologies, although the most commercial post-combustion CO2 capture technologies are liquid amine systems. The Boundary Dam and Petra Nova CCUS projects

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utilize amines to capture CO2 for use in EOR. TCM in Norway and NCCC 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.

In April 2018, Wyoming, the Japanese Ministry of Environment, the Japan Coal Research Center (JCOAL) and Kawasaki Heavy Industries (KHI) announced an agreement to test KHI's solid sorbent technology at the Wyoming ITC. This multi-year project will first test the chemical properties such as absorption and degradation rates of the sorbent. If successful, this could lead to additional systems testing, such as utilizing the sorbent in a fluidized bed system.

The Wyoming ITC also has a relationship with Membrane Technology & Research, Inc. (MTR). MRT is one of ten teams selected for a Department of Energy large pilot demonstration program, which will award up to $40 million to two promising technologies. MTR's technology utilizes selectively permeable membranes to separate the CO2 from the flue gas. It looks more like a reverse osmosis water treatment facility than an industrial plant.

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 on 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 $10 million to 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. Originally, 47 teams from seven countries submitted their concepts to convert CO2 into things like carbon nanotubes, methanol, building materials, fish food and plastics. The goal is to turn CO2 into an asset valuable enough to create an economic incentive to capture CO2.

Earlier this year, ten teams advanced to the final round of the competition based upon their technical and economic merit. Five will test 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.

The five teams coming to Wyoming are from five different countries: The United States, Canada, India, China and the United Kingdom.

Based in India, Breathe is producing methanol, a common fuel and petrochemical feedstock, using a novel catalyst. Carbon Capture Machine, based in Aberdeen, Scotland, is the team is producing solid carbonates with applications to concrete and building materials. C4X is a Chinese team producing chemicals and bio-composite foamed plastics. The American team comes from the University of

California Los Angeles (UCLA) and they will produce building materials that absorb CO2 during the production process to replace concrete. Lastly, Carbon Cure, based in Canada, is producing stronger concrete.

One common theme among all of the finalists is that they are producing products with large markets. With the large amount of CO2 that needs to be managed, the success of conversion technology hinges upon having a large market. While ultimately, we hope there will be a suite of conversion technologies, if everyone made a single product with a limited customer base, the market would be flooded and the economic model would collapse.

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 the 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 attract investors.

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.

Stable, predictable and adequate funding is necessary to commercialize these technologies. On average, it costs about $2-3 million per MW to scale up, meaning that a large pilot could easily cost over $50 million. In the U.S., most researchers rely of cost-shares with DOE. However, the amount of funding available and timing varies and can swing widely depending upon the priorities of the President in office.

Congress may need to look at establishing a program to scale-up the most promising technologies. Finding funding to support a new program is always a challenge, however, the coal mined in the U.S. provides an opportunity. The majority of coal mined in the United States is owned by the federal government and leased to companies. These companies pay a variety of taxes, including federal mineral royalties, bonus bids, Abandoned Mine Land Fees and Black Lung Taxes. Every year, the mineral royalties and bonus bids bring in about $500 million. Over a ten-year authorization, half of that could provide about $2.5 billion to fund carbon management research.

Last year, 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 X Plus has up to 256 GB of storage, facial recognition, multiple cameras 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 the same way we think about 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

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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 provide written comments.

Jason Begger
Executive Director
Wyoming Infrastructure Authority

Jason Begger is the current Executive Director of the Wyoming Infrastructure Authority (WIA). He was raised on a family ranch in eastern Montana and after graduating from college, he moved to Washington, DC, working for two members of Montana's congressional delegation. In Washington, he staffed the 2002 Farm Bill debate and later the Energy and Water Appropriations Subcommittee, focusing on Bureau of Reclamation water projects and Department of Energy Office of Fossil Energy funding. In 2006, Jason accepted a position with the Petroleum Association of Wyoming, before becoming the Manager of Government affairs for Rio Tinto Energy America, which became Cloud Peak Energy. He started with the WIA in July 2015. Jason has a BA in History from Montana State University – Billings and a Master of Business Administration from the University of Denver. Jason and his wife, Kristin, reside outside of Cheyenne, WY.

The WIA is a state instrumentality created by the Wyoming Legislature in 2004 with the mission of facilitate and support the development of energy infrastructure. In August 2015, Governor Matt Mead designated the WIA to lead the construction and development of the Integrated Test Center, which will host CCUS testing.

Chairman WEBER. Thank you, sir. I now recognize myself for five minutes.

Dr. Aines, in your prepared testimony, you highlight the need for national labs and the private sector to work closely together to develop carbon capture, use, and storage technology. And just as an aside, in Port Arthur, Texas, in my district we have probably the largest carbon-capture sequestration unit in the country that I believe was funded by the EERE open—went to the groundbreaking or the ribbon-cutting probably three or four years ago I guess it was.

However, I want to point out it's the ultimate responsibility of industry to commercially deploy these technologies. So, in your opinion, when is the appropriate time for the fossil energy industry to take innovations from the lab to commercialization? And before you answer, do you have like a pipeline of information and research? You're talking with industry consistently so that you're able to keep them up-to-date and then sufficiently or successfully hand that off to them? How do you do that?

Dr. AINES. We do it best when we work in partnership early on, which is why I mentioned this roundtable that we had where we brought industry in to ask them what they wanted to do, and we will be partnering with several of those companies to develop technologies.

The concept of developing and throwing it over the fence, as we call it, does not work well. We need to understand exactly what industry needs and pass it off at the time that they're ready to take it.

Chairman WEBER. Right, and that's why I say not—you know, that's why I say a pipeline of information. You want to keep them involved and keep them working. And I guess you work with some of the associations around that also are very attentive to this process, and they would be able to keep, you know, their members involved so that when we do get to that where it's economically feasible, viable, then you can hand that off. Do you have those relationships established?

Dr. AINES. Yes, sir. We try to develop those, but I have to say that is a major challenge to maintain those relationships because we need things to work on together to actually have a relationship.

Chairman WEBER. No, I got you. What tools do the national labs and the nonprofit research institutions have in your toolkit that make you all better-suited to conduct that early-stage research in support of the innovative technology? How would you describe that toolbox?

Dr. AINES. We have a broad base of science and technology that we can use to look at the whole system. Rather than being an advocate for one particular technology, we like to say what's the problem that needs to be solved and then, you know, somebody of the 7,000 scientists that work at my laboratory is likely to have a solution, and if not, then one of the 17 other national laboratories. So it's important not to be just out there pushing a solution because we have one but to work on the solutions that are required.

Chairman WEBER. Right. And one of those tools we would hope—going back to my previous question—would be that you have robust relationships with industry, maintain those relationships, and keep them interested, so that's a good thing.

Lawrence Livermore National Laboratory, LLNL, what do you all call it?

Dr. AINES. We call it Lawrence Livermore.

Chairman WEBER. Maybe we should call it L's NL, get you a new mantra. All's well and L's NL and so a shorter name would be good.

But you all have supercomputers and tools like carbon-capture simulation, innovative toolset, which provides end-users in the energy industry with computational modeling tools for the development of carbon-capture technologies. So how does L's NL as I call it make sure that academic or energy sector partners can access this research infrastructure and the technical systems the lab can provide? How do you do that, and how often do they access it?

Dr. AINES. We have a mechanism called the CRADA, Cooperative Research and Development Agreement, which we use when working with industry, and we do those commonly. They are a little complicated to put together sometimes.

The second thing that we do that is a new program that has been very effective is called HPC4 Energy. That stands for High-Performance Computing for Energy, and that's a program where the Department of Energy pays the staff at one of the national labs that has expertise to work with an industry problem. The industry competes to get their problems worked on, and then we partner to bring the correct expertise to that industry. And that's been an extremely effective way to bring our high-performance computing expertise to the use of industry.

Chairman WEBER. Do you find industry from all across the country or is it more sectionalized if you will?

Dr. AINES. Oh, all across the country. It's a very competitive program.

Chairman WEBER. Does the fact that you're a nuclear weapons lab. Does that hamper or help in that program?

Dr. AINES. I would say it's not a factor.

Chairman WEBER. Not a factor? Okay. Well, I appreciate that. I'm going to yield back, and the Chairman recognizes Mr. Mark Veasey.

Mr. VEASEY. Mr. Chairman, thank you very much.

I wanted to ask Ms. Angielski a couple questions. In your testimony, you describe the challenges of attracting private-sector investment, not only for so-called early-stage technology development activities but for each stage of the path toward commercialization. I was wondering if you could discuss that in a little bit more detail, and also if you could just kind of provide a typical time frame from concept to commercialization and what levels of investment and risk are private companies willing to take so they can deploy these sort of first-of-their-kind technologies without any kind of federal support?

Ms. ANGIELSKI. Certainly. The early-stage research is at a point in time where technical risk is low, as well as cost risk. And so basic research can typically attract both public-sector and private-sector financing, despite what might be long lead times, as you just outlined, for return on that investment. Typically what we see for generation technology, which are very large capital-intensive baseload generation technologies, from concept to commercialization it's typically taken anywhere from 15 to 20 years to actually get a commercialized technology from concept to commercialization, so it's a very long lead time to actually look at what all the scales of development are needed to actually have that technology be able to be operational in commercial practice and then adopted in commercial practice.

So when we look at going from that fundamental basic research, the next step is to scale up to testing those technologies under what we call real operating conditions, and so that requires more investment, you're building equipment and you need to actually spend time operating that facility under those conditions that you can get the operational test data needed to actually scale up and design for a commercial project.

And so as we move through those stages of development and you scale up, it's going to be significantly larger investment in cost, but yet again, your timeline to that return on investment is long enough that attracting both internal financing from companies, as well as private-sector financing can be somewhat difficult to justify, particularly if there isn't a market pool for the technology at that time.

So that's essentially, you know, from just a timeline perspective but also part of the challenge in attracting that private or internal financing. It can be difficult to achieve, which is essential for the federal support to get those technologies actually tested and demonstrated and across the finish line.

Mr. VEASEY. Well, thank you very much.

I also wanted to ask you about the legislation that I'm working on that I mentioned in my opening remarks, H.R. 5745, a bipartisan Fossil Energy Research and Development Act of 2018. You know, it helps bridge the gaps between what the private sector is willing and able to do on its own and what we really need to do to commercialize these technologies at a sufficient pace to meet our national and economic goals. Could you talk a little bit about that?

Ms. ANGIELSKI. So I will say that H.R. 5475—or 5745, I'm sorry, is very consistent with the technology development programs that we have identified in the CERC–EPRI roadmap, which is why we were very pleased to support the legislation. We—the legislation would authorize both basic research, as well as pilot-scale development testing and commercial-scale demonstrations, which we see as critical and necessary for advancing these technologies up to commercialization.

It would authorize carbon-capture projects and accelerate those projects with the funding that's provided through the development or authorization of test centers like those described by Jason both at a small pilot, as well as Jason identified in his testimony, at a pilot scale, which is necessary before jumping to commercial-scale operation.

The legislation also authorizes all of the technology development pathways that we have identified in the roadmap for new power systems, both transformational, as well as other technology-development efforts like high-efficiency materials, for example, that will be needed in order to support those new processes in the future.

And then in order to fully address the reduction of carbon emissions, the legislation also authorizes carbon storage outside of utilizing CO_2 and enhanced oil recovery or converting CO_2 for carbon dioxide, that that will be really important in the future under any scenario in which we find ourselves in a carbon-constrained future, and so that's something we've outlined in our roadmap as well.

Mr. VEASEY. Thank you, Mr. Chairman. I'm out of time. I yield back.

Chairman WEBER. I thank the gentleman. Chairman Biggs, you're recognized for five minutes.

Mr. BIGGS. Thanks, Mr. Chairman.

Again, thanks to all of you for being here today. And Dr. Brun, can you please explain some of the environmental benefits of super-clean CO_2 power cycles?

Dr. BRUN. Basically, what you're doing here is you're providing a power cycle that's more efficient, and that's the first generation of supercritical CO_2 plants. So just by a three to five sometimes seven percent efficiency of a power plant, you're really reducing all criteria emissions by that percentage.

The next generation of supercritical CO_2 plants, which is really what we're looking for as the Holy Grail of supercritical CO_2 is oxy-fuel combustion, and that leads to a potential for a completely carbon-emissions-free powerplant because what you end up doing is you are getting 100 percent concentrated stream of CO_2 at the end that's already pressurized, and so it's ready for sequestration.

So the short-term goal is really an incremental improvement of efficiency, and obviously reduced power cost and cleaner power. The long-term goal is completely carbon-free power plants.

Mr. BIGGS. This leads me to wonder: You must see a path to that. I mean, obviously, you don't know all the technologies and answers, but you do see a path to the Holy Grail I guess?

Dr. BRUN. Yes, we have a development roadmap, and that's Correlated between the different industries. And it's really been a very, very positive collaborative industry, academia and government process, over the last eight years. We really moved the technology forward over the last ten years. Not only on the power-generation side, it takes decades to move any technology forward, and we've really moved supercritical CO_2 in the last eight years from concept to power plant technologies.

So we similarly have a roadmap to get ourselves to oxy-fuel combustion, which is that next level of supercritical CO_2 plant. I would say we're about five to ten years away from that, and there needs to be continued aggressive funding both from industry and from government to achieve that. But right now, I think there's a clear path towards that.

Mr. BIGGS. Okay. So—and when you talked about—in your testimony today, you said we're on the verge of commercial viability. Where in that path do you see commercial viability coming in if we're, what, five to ten years away from oxy-fuel combustion?

Dr. BRUN. Right. It depends on what type of oxy fuel supercritical CO_2 plant you're looking at. So supercritical CO_2 plants at the lower temperatures, for example, for waste heat recovery, those are now commercially available. They have been. You can now go to General Electric or you can go to other companies and say sell me one, and they will sell you one. That was not the case three years ago. That was certainly not the case eight years ago.

We're trying to get to that same level on other technologies like, for example, concentrating solar power, higher temperature supercritical CO_2, so more for fossil-type applications may be in the next three years. Oxy-fuel combustion is probably going to take five years. So some is already commercially available and some is not, and so there is a development path that we need to follow really toward higher temperatures.

Mr. BIGGS. And so what regions of the country or what areas do you see benefiting the most from this technology?

Dr. BRUN. There's really no limits there. This is widely applicable. The nice thing about supercritical CO_2 is that it's site-able anywhere, and it doesn't have any water requirements, and that makes it really site-able in places where you have to have access to water.

Mr. BIGGS. Like Arizona I'm thinking.

Dr. BRUN. Arizona is fine.

Mr. BIGGS. Very good. Thank you. With that, I yield back, Mr. Chairman.

Dr. BRUN. Thank you.

Chairman WEBER. Thank you, sir. The gentleman from California is recognized for five minutes.

Mr. MCNERNEY. Well, I thank the Chairman.

Say, I thank the witnesses. I enjoyed your testimony. I especially thank Mr. Aines and Christie Schomer from Livermore Labs. I've been there many times. It's right inside of my district. I appreciate the work that you're doing over there.

I've often implored my Republican colleagues to embrace carbon sequestration, especially if their districts mine carbon or burn coal or burn coal. That might help them in the long run. Is there anyone on the panel that disagrees with that sentiment?

I see headshaking that they agree with my sentiment. Thank you.

Mr. Aines, you spoke about the need to transfer within the DOD about carbon capture from coal-fired to gas-fired systems, so how do you suggest that we accomplish that?

Dr. AINES. From the DOE.

Mr. MCNERNEY. What did I say, DOD?

Dr. AINES. Yes.

Mr. MCNERNEY. Thank you for the correction.

Dr. AINES. The most important thing is to engage partnerships like what's going on in Wyoming so that the researchers get to work together with industry.

Mr. MCNERNEY. Well, that was simple. So I also appreciate what you said in your written testimony about Mt. Poso Generating Facility in Bakersfield. It's near an oilfield that's well-suited to CO_2 storage. Can you talk more about the policy considerations such as the 45Q credit and California's low carbon fuel standard for incentivizing that development?

Dr. AINES. The issue with carbon capture today is that no one can afford to do it, and so we need incentives to help these first movers get the ability to have a business that's going to make money doing it, just as we did with wind and solar when we first started. Mt. Poso is going to take advantage of two of those, the 45Q tax credit, and within California if you're making a transportation fuel, the low carbon fuel standard as of just last week was trading at $185 a ton of CO_2. So when you combine those two things together, $220, $230 a ton is something that people are absolutely looking at to make real money. And we expect that places like Mt. Poso and places like the ethanol refineries within the central part of the country are going to jump on these opportunities to make money while controlling carbon dioxide.

Mr. MCNERNEY. So do you think that carbon capture and sequestration can be viable without a price on carbon in the long run in the Nation? And also, Ms. Angielski, could answer that question as well.

Dr. AINES. I think that it's a difficult task that is going to require prices like those mechanisms that I just discussed. I don't think we're ever going to make enough money just from selling the CO_2 to do all the carbon management that we need to do.

Mr. MCNERNEY. Thank you.

Ms. ANGIELSKI. I am not sure to—that from CERC's perspective commenting on whether regulation is necessary or not is not a position that we take. I think what we take is the position that Dr. Aines just described, which is improved technology will be needed, particularly for deployment of carbon capture in the power sector.

It, right now, is the differential between the cost of capturing the CO_2, which is where the 45Q credit comes into place to help reduce those costs and actually incentivize the deployment of these technologies in the power sector, as well as in other industrial applications like the ethanol industry, as you just described. However, right now, those credits are not enough to offset the production of CO_2 in the power sector, so that's where we believe that improved technologies through the public-private partnerships with the Department of Energy will help to reduce the cost of applying those technologies in the future. And that will be needed in addition to some of these incentives like 45Q to overall deploy the technologies in the market.

Mr. MCNERNEY. Well, thank you. I'm really interested in the technology, this high-pressure carbon technology, super pressure. Can you describe a little bit, Dr. Brun, the—where that fits in with the Carnot cycle? Where does the Allam cycle fit in with the Carnot cycle?

Dr. BRUN. If you're talking the Allam cycle, I mean—

Mr. MCNERNEY. We're talking about the Allam cycle with——

Dr. BRUN. Yes, that's one of the—there's a host of supercritical CO_2 cycles—supercritical CO_2 really just replaces either steam or water in the cycle, so there is a host of cycle—they're all called Brayton cycle. The Carnot cycle is kind of like the idealized cycle.

Fundamentally, the supercritical CO_2 cycles, the host of cycles, one of them being the Allam cycle—and that's a very promising cycle, by the way—they all end up benefiting the efficiency of the cycle and the power output of the cycle because supercritical CO_2 is really carbon dioxide at high pressure and high temperature—is a much better thermodynamic fluid than steam or air. There's nothing wrong with steam or air. We've been using it for 250 years;

it's good. It's abundantly available obviously, but carbon dioxide is just, from a thermodynamic perspective, a better fuel.

Mr. MCNERNEY. With the Chairman's indulgence, I mean, you're going to have carbon dioxide left over eventually. I mean, you're going to have to do something with it.

Dr. BRUN. Right.

Mr. MCNERNEY. And as it remain pressured after the cycle, you can still——

Dr. BRUN. You can utilize it.

Mr. MCNERNEY. You can use it somehow?

Dr. BRUN. Yes, the beauty of it is that you don't have to do any flue gas or pre-combustion cleanup, right? All this where you need to do something to get the carbon dioxide out of the flue gas, out of your exhaust, you don't have to do that because what you're getting out is 100 percent CO_2 at pressure already, so you don't have to compress it either so you don't have that compression penalties. So you're ready to take that CO_2 and do whatever you want to do with it, sequester it or use it for advanced other products.

That's the nice thing about that cycle whereas in other air cycles you have to take the CO_2 and the stack emissions out of the air at a low percentage, which is expensive. In the CO_2 cycle and the oxy-fuel cycles, you don't have to worry about that. You get pure CO_2 already ready for sequestration.

Mr. MCNERNEY. With the Chairman's gratitude, I yield back.

Chairman WEBER. Absolutely. I think in that instance, Dr. Brun—I don't want to continue this because Mr. Rohrabacher is straining at the halter over there—it's the infrastructure to get that pure CO_2 to work to where it's needed. Is that—isn't that the challenge?

Dr. BRUN. Yes, that's an additional challenge. Obviously, you have to do something with the CO_2 once you have it, right?

Chairman WEBER. Yes.

Dr. BRUN. And so you're still going to need some pipelines. You're going to have to inject it somewhere, into salt domes. All that is additional cost. There's obviously been quite a bit of work in those areas, but, yes, there is——

Chairman WEBER. Thank you. And I thank the gentleman from California. That was a great exchange.

The other gentleman from California, Mr. Rohrabacher, is recognized.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman. And it's been a very interesting discussion. And, I mean, no, I'm not an engineer, so some of the things I'm still trying to come to grips with of how we are accomplishing the various output based on the input and what's in between there. I'm not really sure about some of the engineering.

But the basic motive that we have supposedly or the basic motive behind much of what's going on about CO_2 is based on the theory that CO_2 is a major factor in causing our planet to get hotter and hotter. I don't happen to agree with that. I've talked to a lot of scientists who believe that premise is not correct, that looking back at the ice cores from ancient times to now actually has the planet getting hotter, and then there's more CO_2 being created.

I'm not going to ask you what your beliefs are on CO_2 making the planet hotter. Let's just accept that today there—also, the discussion today is based on there's CO_2 that's being produced. Can we do something that is beneficial to mankind even if you do not believe that CO_2 is causing the planet to get hotter? And that discussion I think is very important for all of us to make, and we're very happy to have you here to help direct that discussion.

In my own area in Orange County we have a company called Newlight Technologies. Are you aware of this company? I'm very proud of these young men, who are surfers and went off to Princeton and got educated and realized that there was a potential for getting something out of the air, straight out of the air that would be of value. And they have just opened up their first $50 million production site after spending years perfecting it.

And let me just note for the record here its Newlight Technologies, and they are taking carbon dioxide and methane emissions right out of the air and producing high-quality plastic that is actually at a lower cost than the current method of producing plastic. And the plastic that they are producing has biodegradable properties that make it even more important because whales that are eating plastic bags, we know that's bad and we don't want fish and other ingestion of plastic is actually harmful for the environment.

These kids are taking that CO_2 out of the air and the methane out of the air and producing things that are cheaper and better. And so I think that's a formula for progress. And so whatever we do, we need to make sure that actually there is not just the benefit of keeping the planet from warming but instead other benefits that go with that.

Now, I'd like to talk about that. I'd like to ask about whether or not—when we're talking about the Colorado—or the Wyoming projects and—that are going on or—we have—well, let me talk about the scrubbers first and all the—what you presented for us, Dr. Brun, was very complicated. And again, I was trying to get a non-engineer to understand this. In the end, are you coming up with a product that actually is going to be cost-effective, or is this going to be at an enormous cost?

Dr. BRUN. No, all the models are predicting that it's cost-effective. And what's important here is that this is not done in a vacuum. We are working with industry. We're working with all the major power players in the United States and companies like General Electric and others that are investing significantly of their own money, so they're not just taking DOE money to develop this technology; they're investing their own money. And so they're clearly seeing commercial viability in that technology; otherwise, they wouldn't be pursuing it.

Mr. ROHRABACHER. So this would be economically viable in and of itself?

Dr. BRUN. That is the aim.

Mr. ROHRABACHER. Okay.

Dr. BRUN. Yes.

Mr. ROHRABACHER. And, Dr. Aines, in your prepared statement, you mentioned the potential growth for using carbon for manufacturing in industry and both carbon dioxide and natural gas will be the main inputs for industry. And when you think about natural gas and both carbon dioxide and natural gas being used as inputs for this or for a—so why do we need to then have tax benefits and R&D funding for all fossil fuels if indeed we're just talking about the natural gas and carbon dioxide?

Dr. AINES. I can't answer that question in detail. I look to the future, and I see that industry is very interested in using natural gas because of the simplicity and the cleanliness but mostly the simplicity and its lower cost for them, and so that is where the direction that a lot of industrial movers are going.

Mr. ROHRABACHER. Well, when it comes to CO_2 and—you know, I drove across the country with my family a year ago, and one thing that was interesting for my kids was to see all of these fields that were covered with plastic and machines pumping something into that plastic with the different plants like tomatoes, et cetera, and they were—my kids were very surprised to find out that they were pumping CO_2 into these big coverings of agricultural products. Is—the end-situation there we're utilizing CO_2 for something that's positive. You get more food out of it. Is that—so is this not an example—is there more examples like this that we could have that would actually—where we're using CO_2 that will in a way benefit—like our friends are making plastic out of it. Are we going to see more of this? And maybe you have some examples specifically of how CO_2 will be used to have other uses that are beneficial.

Dr. AINES. That's a great example, and another example that I would point to is the addition of carbon dioxide to cement and concrete, which I know of about 20 companies that are pursuing this. And the major advantage there is it makes the concrete stronger, and so you can use less of it, you can have a more efficient structure, and it's a terrific combination of having a better product and using the CO_2 that we want to keep out of the air.

Mr. ROHRABACHER. So we don't have to really agree on whether or not global warming is caused by CO_2 to be very interested in this whole concept of science research and expanding the use of CO_2 in a positive way.

Chairman WEBER. You don't. You just have to agree and yield back.

Mr. ROHRABACHER. Thank you.

Chairman WEBER. Okay. All right. The Chair now recognizes the gentleman, Mr. Tonko, for five minutes.

Mr. TONKO. Thank you, Mr. Chair, and thank you to all of our witnesses for being here today.

This is a critical topic because a modern society needs energy, and the only way we are going to meet our energy challenges are through investments in research and development. We often hear about the need to reduce government spending, and while that is certainly important, we cannot lose sight of the vital role the government plays in investing in innovation.

The Federal Government must be an active partner with universities, with independent laboratories, and certainly the private sector. The only way we are going to meet our energy challenges are through investments in research and development. Having an R&D portfolio that covers the spectrum from basic sciences to technology development, testing and deployment greatly augments the work being done by the private sector and in our university communities.

Sustained support of these efforts is essential to lowering costs and improving performance of energy technologies. And when it comes to a national energy policy, there are so many areas that we should be further discussing, including battery development, storage, alternative energy, grid investments, energy efficiency and innovation, and how we generate and transmit and conserve power.

This committee should be looking at how we can invest so that our Nation can have the best options to choose from to ensure that we protect our Nation by addressing our national security and our public health and our Nation's economy. I fully believe that across the field we need to develop technologies to reduce our carbon footprint and to increase efficiency in all areas, which is why I'm so proud of being a supporter of a bill to make gas turbines more efficient.

Efficiency must be our fuel of choice, especially for fossil fuels. The gas turbine R&D bill, which I have worked on with Representative David McKinley, would authorize DOE's Office of Fossil Energy to carry out a multiyear, multiphase R&D program to improve the efficiency of gas turbines used in power generation systems and to identify the technologies that ultimately will lead to gas turbine combined-cycle efficiency of some 67 percent. This includes high-temp materials, improved heat transfer capability, manufacturing technology required to construct complex parts, advance controls and systems integration, among other topics. And expanded government investment and research of gas turbine technology will lead to more American jobs, increased American global competitiveness, and reduce greenhouse gas emissions.

So for all of our witnesses, how important do you think it is that we use our fossil fuels more efficiently if we continue to rely in part on them? Anyone?

Ms. ANGIELSKI. I'm happy to answer. I think historically, we've seen the benefits from improved efficiency in both gas turbines through natural gas combined-cycle systems, as well as coal-fired generation. And with every percentage point in improvement, we see a significant reduction overall in emissions, as well as fewer fossil fuels being needed for that same amount of energy output. So it's very, very important.

Mr. TONKO. Anyone else? Thank you.

Mr. BEGGER. Yes. Mr. Chairman, Congressman, I completely agree. You know, if you look back at the power plants, you know, this generation of power plants have been retiring in the last few years that were constructed in the '60s and '70s, you had maybe a 30 percent efficiency factor. Today's power plants, you look at the Turk facility in Arkansas, which is supercritical, it's up over 40 percent. So one thing that if the United States wanted to improve efficiencies and emissions today is you would find a way to build more of those supercritical Turk plants and close down the older plants because efficiencies do matter and they do get us there.

Mr. TONKO. Oh, yes. They address the amount of electrons we can save and the dollars we can save, so yes, sir. Dr. Brun?

Dr. BRUN. Yes. I think gas turbine development is a really wonderful example of how you have a collaboration between academia, government funding, and industry, specifically GE in the United States and Westinghouse before, where you've taken a technology from after World War II maybe in the 30 percent efficiency to now we're talking 67 percent efficiency, which is by far the highest efficiency power plant technology that's out there. That's higher than anything else, and that's—I mean, that's been dramatically—even over the last 20 years we've gone from about 55 to about—right now, we're probably at 63, 64, but we're aiming for that 67 percent. So that research has been fantastic, and every percent that you save is one percent less CO_2——

Mr. TONKO. Right.

Dr. BRUN. —and is one percent less fuel burned, and so that's been very effective research, and that's been a great collaboration between industry and government and academia.

Mr. TONKO. Right. It's hard to believe that there are think tanks out there that fight this effort to offer these challenges, develop these goals, and reduce the pollution, the carbon pollution, but they're there and it's a force we have to work against.

So with that, I thank you all for your input and I yield back, Mr. Chair.

Chairman WEBER. Thank you, Mr. Tonko.

And the gentleman from Texas, Dr. Babin, is recognized for five minutes.

Mr. BABIN. Yes, sir. Thank you, Mr. Chairman. And I appreciate all of you being here today, very, very interesting.

Mr. Begger, can you please describe the misconceptions that many people have of coal and why technological innovation can help clear up some of these misconceptions? If you would elaborate, please.

Mr. BEGGER. Mr. Chairman, Congressman, one of our biggest goals—I mean, the reason why Wyoming is involved in this is to figure out how can we ensure the long-term viability of a natural resource the State has. You know, 1/3 of Wyoming's tax revenue is directly dependent upon the coal industry. The benefits of coal are pretty evident. It's the reason why the country has been using it for years. It's why China is using it. Why we see these industrialized nations using more and more of coal is it's reliable, it's stable, you can put it on a pile somewhere, you don't need a pipeline. It is a very great fuel for beginning an energy industry.

And so I think our challenge now is how can we use that, understanding society's drive and demand towards lower carbon standards? You know, in the past, you know, nobody talks about acid rain anymore. It's because we've developed scrubbers. The smog, you know, you'd see those old pictures from Pittsburgh and, you know, Detroit 50 years ago. We don't have those sort of things anymore because we've developed, you know, baghouses and electrostatic precipitators.

And so Wyoming's approach is let's look at climate change as a political—or, excuse me, as an engineering challenge and not a political football because industry time and time again has shown that, given enough time and enough resources, we can engineer a solution——

Mr. BABIN. Absolutely.

Mr. BEGGER. —and find that win-win. You know, let's remove CO_2 and we can find an economic incentive to do so, that's great.

Mr. BABIN. I appreciate that. It's very fascinating. And being from Texas, my district is over on the east side where we produce a lot of natural gas, and yet 60 percent of our electricity in my district comes from coal, coal-fired plants. Thank you very much.

Dr. Aines, your research—excuse me. In your prepared testimony, you mentioned the carbon economy and the future potential for growth and utilizing carbon as an input for manufacturing or industry. Both carbon dioxide and natural gas will be the main inputs to produce products from a carbon economy. Why is it important to have fossil energy research and development funding focused on all fossil fuels?

Dr. AINES. There are many options needed in an economy as large and diverse as ours, and we simply can't afford to pick winners. It's certainly not my job to pick winners. It's my job to deliver solutions, and that's why we need research across the entire gamut.

Mr. BABIN. Thank you very much.

And, Dr. Brun, in your opinion, if you've already spoken about this, stop me, but I didn't—I don't think you have. Will supercritical carbon dioxide power cycles begin to replace traditional steam and air cycles? And could investments by the energy sector in supercritical carbon technology help us to continue to take advantage of our abundant and affordable fossil energy?

Dr. BRUN. Yes, I think we can see on the low temperature wasted recovery side we can probably see something in the next three to five years. Obviously, there is hundreds and hundreds of powerplant, so it's not just an easy replacement. But I can foresee in the next 10, 15 years quite an impact from supercritical CO_2 and replacement of it, especially of steam cycles. On the air cycles, that's gonna take a little longer, but probably 10 to 15 years.

Mr. BABIN. Okay.

Dr. BRUN. The technology is moving fairly fast there.

Mr. BABIN. Glad to hear.

And, Ms. Angielski, can you give an example of carbon capture, utilization, or storage research through investments by fossil energy industry that could lead to an advanced carbon-based technology?

Ms. ANGIELSKI. There are several that were discussed here today, so certainly the supercritical CO_2 cycles. We identify several technologies in our roadmap, including pressurized oxygen combustion, which was described here today. We have some carbon-capture technologies that are looking for testing right now that, once tested, could actually begin to have commercial offerings available. So there are a suite of technologies, which, from our perspective, is very important to make sure that we have a diverse portfolio of technologies and that we're not just picking winners, as already discussed.

Mr. BABIN. Right.

Ms. ANGIELSKI. And so—but there are several technologies identified in the roadmap that are readying for that testing to be able to then take that piece of paper to a financer and say we can offer commercial guarantees. So——

Mr. BABIN. Thank you. And I yield back, Mr. Chairman. Thank you.

Chairman WEBER. Thank you, Doctor.

The gentleman from Alabama, Mo Brooks, is recognized for five minutes.

Mr. BROOKS. Mr. Chairman, I'll defer.

Chairman WEBER. Then the other gentleman from Alabama—we've got both of them here today—is recognized for five minutes, Mr. Palmer.

Mr. PALMER. The one who will not defer. Thank you, Mr. Chairman.

This is very interesting to me. I've worked for two engineering companies prior to running a think tank for 24, 25 years. I worked for Combustion Engineering and Environmental Systems Division. I see Dr. Brun nodding his head. We built scrubbers, precipitators, baghouses.

And I just was wondering on the latest technology how effective are we at capturing CO_2 right now, Dr. Brun?

Dr. BRUN. It depends on how concentrated your stream of it is. If you're doing flue gas—I mean, you can capture 100 percent of it, right? I mean, it's technically viable. It becomes a cost issue. So it's easier to—the more concentrated your stream and your flue gas is, the easier it is to capture it. And that's why we're pushing for the oxy-fuel and supercritical CO_2-type cycles, but you can certainly remove CO_2 from the flue gas of a combined cycle plant.

The only problem is that it is a low percentage, and so you have to scrub a lot more gas to get the CO_2 out. But even there you can remove 100 percent of the CO_2. It just becomes a cost-of-electricity issue and how much cost you want to add to your cost of electricity. There's a technology there in that sense exists, and it's just a question of cost.

Mr. PALMER. Well, one of the reasons I'm asking this is that when it comes to fossil energy, most of the time we're talking about—when we're talking about capturing carbon, we're talking about coal, but there are uses or potential uses for capturing CO_2 for unlocking oil resources from shale. And we've got the Green River Formation. Are you familiar with that?

Dr. BRUN. No, I'm not.

Mr. PALMER. The Green River Formation—and I have a GAO report, which was part of a committee hearing I think in 2012 that got very little attention in the media. ABC News reported on it. But the Green River Formation holds three trillion barrels of recoverable oil. That's three times what the entire world has used in the last 100 years and five or six times the known reserves of the Saudis. Just half of it would be more than the known—all of OPEC combined. About half of it, 1.4 trillion, is the more recoverable, the richer deposits. But in your research do you see the potential for using captured carbon for releasing or having access to such oil deposits?

Dr. BRUN. Yes, I think using CO_2 for enhanced oil recovery is certainly a recognized usage of carbon dioxide, and the combination of oxy-fuel combustion plants where you get CO_2 out and then you inject that at high pressures into the formation to get enhanced oil recovery is something that has been discussed by many oil companies. I've given presentations on the topic actually. It's certainly a viable technology for——

Mr. PALMER. But is it economically viable?

Dr. BRUN. Yes, it is. It is economically viable. It depends on your formation. It depends on your application, but there are certainly applications right now where it is economically viable, yes.

Mr. PALMER. Do the Chinese or the Indian Government do anything in regard to carbon capture?

Dr. BRUN. The Chinese are doing quite a bit in that area. Maybe you can answer that, too, but——

Mr. PALMER. Yes, anyone of the panel if you know the answer to that.

Dr. BRUN. Yes, the Chinese are very active, but you may have more information.

Dr. AINES. Yes, the Chinese are in fact the most active nation in the world in this area doing large demonstrations and developing their own technology. The Indian Government has done very little to this day.

Mr. PALMER. And the Indian economy is the fastest growing economy in the world, and they're building quite a—done quite a bit of building in regard to coal-fired power-generating facilities. Is that accurate?

Dr. AINES. They are still building coal plants. It is decreasing there. They are building more renewables now than coal.

Mr. PALMER. Good. Mr. Begger, in your testimony you mentioned the partnership between the Wyoming Integrated Test Center and the National Carbon Capture Center near Wilsonville, Alabama. That, by the way, is in my district. Can you give us a little more detail about the work that ITC intends to do through this partnership?

Mr. BEGGER. Sure. Mr. Chairman, Congressman, the way that we see our role is complementing the work that National Carbon Capture Center, NETL, and the other labs have done. And a few years ago the state was looking about how to best get involved. And through the course of about a year and a half of reviewing critical gaps in testing infrastructure, what we recognized is that there are a lot of places to do small testing like the National Carbon Capture Center, on the backside of that coal-fired power plant, they could test up to about 1–1/2-megawatt-size projects. But utilities needed to see something larger before making that leap.

And up until now really the only way to do that was a one-on-one relationship between the technology developer going to a utility and asking to basically cut a hole in the side of their power plant and access some of their flue gas. And, as you can imagine, they were pretty reluctant to do that unless there was a long-standing relationship. So what we've done with that facility is sort of create the infrastructure there, a plug-and-play system.

And so what we would like to see, the most promising technologies that make it through there be that sort of graduate school for them to come and test. And another area is access to all of the incredible resources. You know, over years at Wilsonville, they've developed incredible institutional knowledge, engineering skills, and so having the ability to basically access their lessons learned and their best practices can hopefully help us prevent making those sort of same mistakes.

Mr. PALMER. Well, this is all fascinating to me, Mr. Chairman. I, as I said, worked in engineering and environmental systems, and my brother-in-law worked for Southern Research and was an expert in scrubbers and baghouses, traveled all over the world. I would love for him to have been here. He probably would have had some better questions than me.

With that, Mr. Chairman, I yield back.

Chairman WEBER. I thank the gentleman.

The Ranking Member from Texas is recognized for another question.

Mr. VEASEY. Thank you, Mr. Chairman.

Ms. Angielski, you know, as you know—and you've seen it on the news—the current Administration has strongly opposed practically any regulating of greenhouse gases. And many including the President and our former EPA Administrator have publicly questioned the validity of the broad scientific consensus on the current and growing threat of climate change.

So in this context, please help us to a better understand why are there Carbon Utilization Research Council industry members like Peabody, Arch Coal, and the American Coal Council so supportive of developing carbon capture, utilization, and storage technologies that may ultimately impact their profits if they're ever required to deploy them? If you could kind of help us understand that, I think it would really go a long way.

Ms. ANGIELSKI. Sure. Well, as indicated in my testimony, there's growing international use of all of our fossil fuel resources, and as a result of that, there's growing international consensus that we will need to do something to reduce the carbon footprint from the utilization of the fossil fuels. That's the position that we take when we look at evaluating technology development needs both for today, as well as what we're going to need in the future.

As a result, and as I mentioned earlier, a lot of that focuses on the ability to reduce emissions of CO_2 and carbon dioxide. I think what's equally important about that is that many stakeholders, not just industry stakeholders but also those in the environmental community, also share in that consensus, which is we recognize the growth in these fuels and we will need to invest in these technologies in order to achieve any global climate objectives.

At the same time, we've also heard that there's both environmental benefits from investing in these technologies, as well as economic benefits, and that's also another perspective that we take. When you look at these environmental benefits, for example, lower-cost CO_2 will be needed for enhanced oil recovery in the future. We have less and less CO_2 coming from natural sources that are currently mined and used for producing more oil from our depleting oilfields in this country. So a lot of the oil companies in this country are looking to power generators for those large volumes of CO_2 coming off of fossil fuels to be able to use that in enhanced oil recovery. So we're looking at that as a market opportunity as well.

If we have, as was described earlier, maybe a waste product and CO_2 being vented in a flue gas stream, why not put that to good use and get some economic value out of it while also producing more domestic oil and ultimately producing a low-carbon barrel of oil as well, which is important to recognize?

So there's both tracks that can be pursued. I think over the long term if—under any future scenario, I think we share a view that we may be living in a carbon-constrained world, and we want to make sure that we have those technologies available to enable us to continue to utilize our fossil fuel resources and to have them being competitive with all of the other low-carbon generation sources that are available to us today as well.

Mr. VEASEY. Mr. Chairman, I yield back. Thank you.

Chairman WEBER. I thank the witnesses for their testimony and the Members for their questions. The record will remain open for two weeks for additional written comments and written questions from members.

The hearing is adjourned.

[Whereupon, at 11:50 a.m., the Subcommittees were adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Jason Begger

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"The Future of Fossil: Energy Technologies Leading the Way"

Mr. Jason Begger, Executive Director, Wyoming Infrastructure Authority

Questions submitted by Rep. Daniel Lipinski, House Committee on Science, Space, and Technology

Mr. Begger, in your testimony, you described your organization's partnership with the XPRIZE Foundation and your involvement in the NRG COSIA Carbon XPRIZE. You also said that Congress may need to look at establishing a program to scale up the most promising technologies, similar to what XPRIZE is doing. I agree with you that the government should play a key role, and earlier this year, I introduced H.R. 5031, the Challenges and Prizes for Climate Act, which would create federally-sponsored prize competitions in five key technology areas, including carbon capture and use. The competitions would be run by DOE and would provide a forum for the government's leading energy experts to interact with the cutting-edge technology developers.

1. **I wanted to ask you what the benefits are of competitions like these being run by the government, as opposed to foundation-led efforts like XPRIZE. Are there particular types of problems that are better solved by the public vs. the private sector? Are there certain solver communities that are better engaged by publicly- or privately-run challenges?**

Historically, inducement prize contests (IPC) have been offered by both public and private entities. Some of the more notable private prizes are the Orteig Prize, awarded to Charles Lindbergh for the first non-stop flight between New York and Paris; the Ansari XPRIZE, for space flight; and the Virgin Earth Challenge, for permanently removing greenhouse gasses directly from the atmosphere.

Over the years, governments have hosted the majority of IPC's, many in support of war efforts. The Longitude Rewards were a series of prizes hosted by the British government to find ways to accurately determine a ship's location while at sea, and in the 1800's the French provided a prize for food preservation.

Most IPC's have focused on solving some sort of challenge for the greater good of humanity and benefitting society as a whole. Many would say the role of the government is to tackle these types of issues as they have the greatest ability to create a Research and Development program with a long-term view that does not have the same economic pressures to produce a speedy return on investment required by the private sector.

Establishing, monitoring and managing a prize competition is not simple or inexpensive. In my opinion, a successful IPC needs the following:

1. A guaranteed prize amount, large enough to justify the investment risk for participants. Carbon capture is very expensive to construct and operate, so a prize would need to be attractive enough to spend millions to design, construct and operate the project.

2. An organization with the resources and funding to administer the competition, which includes writing the rules, ensuring all participants adhere to the rules, provide technical support and maintaining the integrity of the competition.

3. A suitable, neutral location to conduct the competition. The Ansari XPRIZE utilized the Mohave Spaceport, which was a repurposed, former military site. The NRG COSIA Carbon XPRIZE will test, in-part, at the Wyoming Integrated Test Center (ITC).

The XPRIZE Foundation, has established a successful IPC model which utilizes sponsors to fund the prize amount, internal staff to administer the competition, and contracts with outside facilities for the competition locations. Above and beyond great competency in running IPC's, XPRIZE also looks beyond the competition and marketing the IPC to bolster commercialization of technologies. By partnering with potential investors, technology licensers, and product customers; they assist the competitors by creating an environment where the best ideas can be quickly adopted by the private sector whether or not a particular project wins the final competition. The best-case scenario is when an IPC leads to more than one technology advancing to commercialization, not just one winner.

Wyoming's experience with the NRG COSIA Carbon XPRIZE competition has been very positive. The ITC is also actively pursuing projects that have advanced through traditional means, such as Department of Energy grants. However, many of the teams that are participating in the XPRIZE competition come from small labs or universities that are new players in the carbon technology space. This does create new challenges and we are finding that many of them do not have the same experience with regards to project implementation, but these are technical obstacles that can be overcome. If the goal is to test and advance many different carbon management technologies, XPRIZE has successfully found and appealed to a new pool of researchers.

Private companies are not likely to play leading roles in IPC's. They required to act in the best interests of their shareholders and in some cases with publicly traded companies, Securities and Exchange Commission (SEC) rules emphasize fiduciary responsibility and limit the types of risks can be taken with shareholder funds. There are examples of private companies offering IPC's, but most are small and very narrowly tailored to the best interests of the company, such as providing a public relations value. One example of a company playing a major role is NRG Energy, which is a title sponsor of the NRG COSIA Carbon XPRIZE. Being privately held, NRG has more latitude than a publicly traded company.

An important consideration when establishing an IPC and determining the best structure for managing the competition is risk tolerance. Typically, in government programs, the fear of jeopardizing taxpayer dollars and any associated negative publicity with failure leads to a very low tolerance for risk. Oftentimes government decision making prioritizes analysis over action.,

Appendix II

Additional Material for the Record

DOCUMENTS SUBMITTED BY SUBCOMMITTEE RANKING MEMBER VEASEY

AMERICAN FEDERATION OF GOVERNMENT EMPLOYEES, AFL-CIO

Joseph P. Flynn *National Secretary-Treasurer* | **J. David Cox, Sr.** *National President* | **Augusta Y. Thomas** *NVP for Women & Fair Practices*

July 17, 2018

The Honorable Lamar Smith
Chairman
House Science Space and Technology Committee
2409 Rayburn House Office Building
Washington, DC 20515

The Honorable Eddie Bernice Johnson
Ranking Member
House Science Space and Technology Committee
2468 Rayburn Office Building
Washington, DC 20515

Dear Chairman Smith and Ranking Member Johnson,

On behalf of the American Federation of Government Employees, AFL-CIO which represents over 700,000 federal and D.C. government workers in over 70 agencies across the country including hundreds of scientists, engineers and technicians at the National Energy Technology Laboratory (NETL), I write to indicate my support for H.R.5745, the Fossil Energy Research and Development Act of 2018 and the overall strengthening of fossil energy technology.

AFGE represents employees at the National Energy Technology Laboratories (NETL). NETL is the only Government-owned-and-operated National laboratory out of all the 17 national labs. NETL employees work primarily on fossil energy research. The core programs throughout NETL's history have been in the research and development of technologies for coal, oil and gas. NETL scientists develop safer and cleaner methods of extraction and processing of fossil fuels which account for 80% of energy use nation-wide. In addition, their research on rare earth mineral extraction is vital for the continued use and growth of solar panel energy, and it was their research that developed the carbon capture technology in use today.

We thank the House Science Space and Technology Committee for holding this hearing on fossil energy technologies and we commend the committee for strengthening NETL and the important work they do for the American people. We thank the committee for working closely with AFGE to improve research and development of fossil energy technology. We look forward to working with the committee in the future to improve NETL facilities, employee working conditions and the future of fossil energy technology. We strongly support the work the committee does for NETL employees and we support H.R.5745, the Fossil Energy Research and Development Act of 2018. For questions please contact Fiona Kohrman at fiona.kohrman@afge.org.

Thank you,

Thomas S. Kahn
Director, Legislative Affairs

80 F Street, N.W., Washington D.C. 20001 · 202.737.8700 · Fax 202.639.6490 · www.afge.org