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FOSSIL ENERGY RESEARCH: ENABLING OUR CLEAN ENERGY FUTURE

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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C O N T E N T S

June 19, 2019

FOSSIL ENERGY RESEARCH: ENABLING OUR CLEAN ENERGY FUTURE

WEDNESDAY, JUNE 19, 2019

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

The Subcommittee met, pursuant to notice, at 3:25 p.m., in room 2318 of the Rayburn House Office Building, Hon. Conor Lamb [Chairman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY
U.S. HOUSE OF REPRESENTATIVES
HEARING CHARTER

Fossil Energy Research: Enabling our Clean Energy Future
Wednesday, June 19, 2019
2:00 PM EST
2318 Rayburn House Office Building, Washington, D.C. 20015

PURPOSE

The primary purpose of this hearing is to examine research and development needs to mitigate the environmental impacts of the extraction and use of fossil fuels. The hearing will focus on two draft bills: 1) the Fossil Energy Research and Development Act of 2019, to support research, development, and demonstration activities in carbon capture, storage, utilization, and removal; efficiency improvements; and mitigation of methane leaks from natural gas infrastructure, among other areas; and 2) the Industrial Decarbonization Technology Development Act of 2019, which authorizes a cross-agency but Department of Energy-led research program to develop technologies that will help decarbonize industrial processes and long-distance transportation, including emissions from steel and cement production, chemicals production, the generation of heat for industrial processes, heavy road and rail transport, shipping, and aviation.

WITNESSES

- **Ms. Shannon Angielski**, Executive Director, Carbon Utilization Research Council
- **Mr. Elgie Holstein**, Senior Director for Strategic Planning, Environmental Defense Fund
- **Mr. Jeff Bobeck**, Director of Energy Policy and Engagement, Center for Climate and Energy Solutions
- **Ms. Erin Burns**, Director of Policy, Carbon180
- **Dr. Erik K. Webb**, Senior Manager, Geoscience Research and Applications, Sandia National Laboratories

BACKGROUND

Department of Energy, Office of Fossil Energy (FE)

The DOE Office of Fossil Energy (FE) supports research to develop new technologies and methods to reduce the environmental impact of fossil fuel production and use, with a major focus

on the capture and storage of carbon dioxide emissions. A portion of this research also focuses on improving the efficiency of fossil fuel power plants. Coal and natural gas account for about 56% of electricity generation and will likely continue to be a major part of the U.S. energy portfolio in the decades to come.[1] However, financial analysts have determined that greenhouse gas emissions and other pollution associated with fossil fuels add risk to investing in these technologies in the long-term.[2] Developing environmental mitigation strategies for these resources is not only an environmental concern, but also an economic one for these industries.[3] Moreover, while carbon emissions growth has leveled off in the United States in recent years, this is due mainly to the transition from coal to less expensive natural gas. Studies have found that this transition to natural gas alone is unlikely to be sufficient to mitigate the most significant potential impacts of climate change.[4,5,6] The International Energy Agency has projected that deploying carbon capture on natural gas fired power plants will likely be critical to meeting meaningful emissions reductions targets in the long term.[7]

FY 2020 Office of Fossil Energy R&D Budget

FY 2019 Enacted:	$ 740 million
FY 2020 Budget Request:	$ 562 million

The President's Fiscal Year 2020 budget request would, if enacted, reduce federal support for FE R&D activities by 24% from the FY19 enacted level. This would include a 65% cut for carbon capture, utilization, and storage R&D and a 40% cut for research activities to reduce emissions from the extraction and use of natural gas.[8]

[1] Annual Energy Outlook 2018, U.S. Energy Information Administration, https://www.eia.gov/outlooks/aeo/
[2] Morgan Stanley, "Is the Climate Changing for Fossil Fuel Investments?", October 9, 2018, https://www.morganstanley.com/articles/fossil-fuels
[3] Risky Business: The Economic Risks of Climate Change in the United States, 2014, https://riskybusiness.org/report/national/; and Risky Business Project, From Risk to Return: Investing in a Clean Energy Economy, 2016, https://riskybusiness.org/fromrisktoreturn/.
[4] Hirji, Zahra, "Slowing Climate Change Will Require Vastly More Carbon Capture, Study Says," Inside Climate News, January 30, 2017, https://insideclimatenews.org/news/30012017/global-warming-carbon-capture-paris-climate-agreement
[5] Harder, Amy, "Natural gas is helping combat climate change — but not enough," Axios, June 10, 2019. https://www.axios.com/natural-gas-is-helping-combat-climate-change-but-not-enough-bbad3dd2-b3f8-43bb-827c-ffad24e145c9.html
[6] Roberts, David, "More natural gas isn't a "middle ground" — it's a climate disaster," Vox, May 30, 2019. https://www.vox.com/energy-and-environment/2019/5/30/18643819/climate-change-natural-gas-middle-ground
[7] "Technology Roadmap – Carbon Capture and Storage," http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf
[8] https://www.energy.gov/sites/prod/files/2019/04/f61/doe-fy2020-budget-volume-3-part-1_0.pdf

Deep decarbonization

A number of recent reports have indicated a need for prioritizing the reduction of greenhouse gas (GHG) emissions from sectors beyond power generation, for both economic and environmental reasons.[9,10] In 2017, the transportation sector contributed the highest amount of GHG emissions economy-wide at 28.9%, the power industry contributed the second highest amount at 27.5%, and the industrial sector contributed the third highest at 22.2% of GHG emissions.[11] Despite this, the vast majority of federal R&D investments on emissions reduction technologies and methods in the U.S. have focused on the power sector.

Decarbonization of the industrial sector is particularly challenging due to the variety of products and processes involved, and our nation's historical reliance on these products and processes.[12] Emissions from the industrial sector come from a variety of processes, including: emissions from fossil fuel combustion to generate heat; chemical processes involved in steel and cement production; and the production and use of unsustainable building materials. Thus the technologies to reduce emissions from the industrial sector also take a variety of forms and include investments in: fuel switching; carbon capture; and development of new materials and manufacturing processes.

Department of Energy, Advanced Manufacturing Office (AMO)

Our nation's largest investment in the development of technologies to reduce industrial GHG emissions resides in the DOE Advanced Manufacturing Office (AMO), housed under the Office of Energy Efficiency and Renewable Energy. AMO supports a number of R&D projects and partnerships to develop technologies that enable sustainable and energy efficient manufacturing. For example, AMO funds research on combined heat and power; advanced materials; and digital smart manufacturing. AMO also supports manufacturers through targeted technical assistance and training programs to improve their energy efficiency.

AMO received $320M in appropriations in FY19. The President's FY20 budget request proposed a 74.8% cut to AMO's budget from the FY19 enacted level.

FY 2019 Enacted:	$ 320 million
FY 2020 Budget Request:	$ 80.5 million

[9] Science, *Net-zero emissions energy systems*, June 2018
[10] Third Way, *Industry Matters*, October 2018, https://www.thirdway.org/report/industry-matters-smarter-energy-use-is-key-for-us-competitiveness-jobs-and-climate-effort
[11] EPA report, *Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2017*, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks
[12] C2ES report, *Decarbonizing U.S. Industry*, July 2018

LEGISLATION

Fossil Energy Research and Development Act of 2019

The current draft of the Fossil Energy Research and Development Act of 2019 is an updated version of H.R. 5745 from the 115th Congress, introduced last year by then-Energy Subcommittee Ranking Member Veasey (D-TX), Rep. McKinley (R-WV) and now-Chairwoman Johnson. This bill would reauthorize and expand research, development, and demonstration of carbon capture technologies for power plants and industrial sources. It would also authorize R&D activities in carbon storage, carbon utilization, improvements in efficiency, and rare earth elements. In addition, the bill would launch new initiatives in carbon dioxide removal and methane leak detection and mitigation. Finally, it would authorize special hiring authority and laboratory-directed research and development (LDRD) activities for FE's laboratory, the National Energy Technology Laboratory (NETL) located in West Virginia, Pennsylvania, and Oregon, providing the lab with similar tools that have enabled successful technology development initiatives at DOE's other national laboratories.[13]

Draft Industrial Decarbonization Technology Development Act of 2019

This draft bill directs the Secretary of Energy to establish a DOE-led cross-agency research program to decarbonize non-power industrial sectors. Here, decarbonization is defined as the elimination, to the maximum extent practicable, of net GHG emissions. In particular, the research program focuses on the following:

1) decarbonization of industrial production processes, including: cement, iron and steel production; high-temperature heating processes; chemical production processes including ammonia, ethylene, and propylene production; smart manufacturing; and sustainable manufacturing;
2) alternative materials including: building materials; high-performance lightweight materials; and critical materials and minerals substitutions;
3) decarbonization of liquid and gaseous fuels;
4) decarbonization of shipping, aviation, and long distance transportation;
5) carbon capture for industrial processes; and
6) high-performance computing to develop advanced materials and manufacturing processes.

[13] NETL is unique among DOE's 17 national laboratories in that it is the only one that is government-owned, government-operated (GOGO). The others are all government-owned, contractor-operated (GOCO) labs. According to a 2015 report from the Congressionally-mandated Commission to Review the Effectiveness of the National Energy Laboratories (CRENEL), NETL has thus far been unable to use certain tools and processes that have enabled the flexibility and effectiveness of the other DOE labs. https://www.energy.gov/labcommission/downloads/final-report-commission-review-effectiveness-national-energy-laboratories

The bill also establishes a Federal Advisory Committee that would consist of industry, academic, and federal representatives to help develop the missions and goals of the research program and ensure consistent progress towards achieving these goals, as well as to develop decarbonization roadmaps in each of the relevant focus areas. Finally, the bill authorizes a technical assistance program to allow eligible entities to receive assistance from DOE in working towards the goal of decarbonizing non-power industrial sectors.

Chairman LAMB. OK. This hearing will come to order. Without objection, the Chair is authorized to declare recess at any time.

Good afternoon. Welcome to this afternoon's hearing entitled, "Fossil Energy Research: Enabling Our Clean Energy Future." Thank you to our distinguished panel of witnesses for joining us.

We have discussed on this Subcommittee previously that we all believe we must develop policies that both support American workers while also addressing climate change. I myself believe in a jobs-first environmental policy. That's why I'm excited to hold this hearing. We will focus on two draft bills that will do exactly that today, support critical research to mitigate the environmental impacts that come with the extraction and use of fossil fuels.

Western Pennsylvania, where I'm from, plays a key role in all of this. We are a net exporter of energy, second largest producer of natural gas in the country. We have produced more coal than any State in the Nation, and that has powered us through the Industrial Revolution, two world wars, produced most of the wealth that we enjoy in western Pennsylvania to this day, to say nothing of employing thousands and thousands of men and women supporting families, which also continues to this day.

The energy industry remains a top employer in my district and region. People are working in these jobs and feeding their families tonight with this wealth, and we want to see it continue but in a way that's environmentally responsible and does not deny what we all know is coming with climate change and the urgent need to emit less carbon and decarbonize our economy.

Last month, we were able to have several Members of the Committee join us at the National Energy Technology Laboratory's (NETL's) Pittsburgh site near my district, and we got to see first-hand some of the technologies and works that the folks at NETL are doing. We are extremely proud of NETL and happy that they are under new leadership, which is going to keep them going strong for a long time.

It's the only national lab dedicated to fossil energy research, so we are going to be talking first about the *Fossil Energy Research and Development Act of 2019*, which will support their research activities there. Specifically, I'd like to highlight demonstration activities on carbon capture, and I know some of our folks today will be talking about the importance of that.

We'll also be boosting research to talk about efficiency improvements, the prevention of methane leaks at every point in the natural gas infrastructure, increasing our investment in how to utilize carbon as well.

We also are going to look beyond the power sector in today's hearing, which I think is vitally important. We tend to focus on the power grid, but of course we need to find ways to decarbonize the industrial and transportation sectors as well. So we'll also be looking at the *Industrial Decarbonization Technology Development Act*—it really rolls off the tongue—the IDTD. The bill would authorize an interagency research program led by DOE (Department of Energy) to develop technologies that will help us eliminate lifecycle greenhouse gas emissions from both the industrial and transportation sectors.

This can and should be a bipartisan issue, and I believe it will be based on conversations with my colleagues. Secretary Perry has said that you cannot have a real conversation about clean energy without talking about CCUS (carbon capture, utilization, and storage). Former Secretary Moniz has made very similar comments. The Department of Energy under the Obama Administration released a white paper on this technology saying that CCUS would be a key pathway to where we need to go on clean energy. And of course, as at least one of our witnesses has noted in their written testimony, the IEA (International Energy Agency) has also noted that it could be 2 or 2-1/2 or 3 times more expensive to reach our climate goals by 2050 if we do not have carbon capture as part of the solution.

So I think we're all on the same page there. We will do everything we can to push forward this knowledge and then have this also be a source of American jobs in the future because we all believe that others in the world will be burning fossil fuels for a long time. We might as well have them buying carbon capture technology from the United States.

So I thank our panel of witnesses again for being here today, look forward to your input.

[The prepared statement of Chairman Lamb follows:]

Good afternoon and thank you to this distinguished panel of witnesses for joining us today. As we've discussed on this Subcommittee previously, we must develop policies that strongly support American workers while addressing the critical issue of climate change. I believe Carbon Capture, Utilization, and Storage technologies represent that type of dual opportunity. That is why I am excited to hold today's hearing, which focuses on two draft bills that would support critical research activities to mitigate the environmental impacts that come from the extraction and use of fossil fuels and curtail emissions from the industrial sector.

Western Pennsylvania plays a key role in this intersection. Pennsylvania is a net-exporter of energy and the second-largest producer of natural gas in the country. My home state has produced more coal than any other in our nation's history - coal that powered us through the industrial revolution and two World Wars. We used this power and our resources to make the steel that built our country.

These industries employed thousands and thousands of men and women; generations supported their families through this hard work. That continues to this day. The energy industry remains a top employer in my district and region, and we have world-class labs, companies, and universities conducting cutting-edge research to ensure these resources and products are made in environmentally responsible manners.

Last month, I was very proud to lead a Congressional Delegation to the National Energy Technology Laboratory's (NETL's) Pittsburgh site near my district, where we saw first-hand the wide range of important technologies and methods that NETL is developing to ensure that the production and use of coal and natural gas are as efficient and environmentally friendly as possible. NETL is the only U.S. Department of Energy national laboratory dedicated to fossil energy research.

Accordingly, I'm pleased we are holding this hearing on the *Fossil Energy Research and Development Act of 2019*. This bill will support research, development, and demonstration activities on carbon capture, storage, utilization, and removal and bolster the work being done at NETL. It will also boost research to advance significant efficiency improvements, prevent methane leaks from natural gas infrastructure, and increase our investment in carbon utilization research.

As we continue to develop ways to reduce the environmental impact of fossil energy sources overall, we must also look beyond the power sector. The industrial and transportation sectors combined produced nearly half of all greenhouse gas emissions in the U.S. in 2017. The second draft bill we are considering today, the *Industrial Decarbonization Technology Development Act of 2019*, is aimed at mitigating that. This bill would authorize an interagency research program led by the Department of Energy to develop technologies that will help eliminate lifecycle greenhouse gas emissions from industrial processes and long-distance transportation. Supporting these types of research and technology can and should be a bipartisan issue.

Secretary Perry has said he doesn't believe "you can have a real conversation about clean energy without including CCUS." I agree.

Similarly, Secretary Moniz often spoke of the importance of CCUS technologies across industries, describing them as "critical for reducing $COCO_2$ and meeting our climate goals," and stating that "we need to continue this innovation push." In 2016, the Department of Energy under the Obama administration also released a great white paper on the technology, heralding CCUS as "a key pathway to address the urgent U.S. and global need for affordable, secure, resilient, and reliable sources of clean energy." We should be doing everything we can to advance these technologies, from their research and development to their deployment.

I thank our panel of witnesses again for being here today and I look forward to their input and feedback on these important topics and the discussion drafts.

Chairman LAMB. And I would like to recognize Ranking Member, Mr. Weber, for an opening statement if he is ready and his breath is caught.

Mr. WEBER. Well, one out of two ain't bad, Chairman.

Chairman LAMB. All right. Go for it.

Mr. WEBER. But I appreciate that. Thank you. I apologize for being late. My bicycle had a flat tire.

Thank you, Chairman Lamb, for hosting this hearing. Today, we will have the opportunity to hear about exciting new research and development in fossil energy.

Last year in the United States, coal and natural gas comprised 64 percent of net electricity generation, with that number expected to only dip to 58 percent by 2040. The use of fossil fuels in the power sector, as you kind of alluded to, isn't going anywhere. We have incredible domestic fossil energy resources, and our economic stability depends on the power they produce.

So it's no surprise that we have a robust industry here at home investing in the generation that you talked about, developing technologies to produce and use American fossil fuels more efficiently, more safely, and at a lower cost for American consumers.

Today's hearing is an opportunity for private-sector organizations and DOE national labs to highlight their leading roles in fossil energy innovation. The scope and range of technologies being pursued is as vast as the untapped oil reserves in west Texas. We'll hear from expert witnesses about research in materials science that can prevent CO_2 leaks in storage formations under high temperatures, high pressures, and chemical conditions.

I'm also excited to hear about a joint project between the Nuclear and Fossil Offices at DOE that uses supercritical carbon dioxide as the working fluid, rather than steam, to dramatically increase energy conversion efficiency at one-tenth the cost.

While there are significant opportunities for worthy and exciting research in this field, it is our job here in Congress to focus Federal agencies on the best use of Federal funds, and that means directing the Department of Energy to focus on the basic and early-stage research industry cannot do on its own. They need to be collecting long-term data and maintaining expertise to provide industry with the tools necessary to achieve technology breakthroughs. Once that technology is developed, industry is best suited to take the lead, building on the DOE research to commercialize those very same technologies.

We've seen incredible research and technology successes through collaborative, public-private partnerships, and it's clear that this is the model that ensures Federal research investments give the

American people the most bang for their buck. One such example is the Air Products production facility in my home district in Port Arthur, Texas. This facility, which is one of only two industrial plants in the entire United States where carbon capture is currently in use at scale, captures over 1 million tons of carbon dioxide per year. Let me restate that. It captures over 1 million tons of carbon dioxide each year. This CO_2 is then transported via pipeline for use in EOR, what we call enhanced oil recovery. With support from the Department of Energy, the technology developed and deployed at this facility is reducing the emissions from local refineries and producing affordable American fuel to power our economy at the same time.

Today, DOE is making smart, targeted investments in early-stage research to advance the next generation of production and emissions control technologies through the DOE Fossil Energy and Research or FER&D program. Funded at $740 million in FY 2019, the FER&D program conducts research that supports clean, affordable, and efficient use of domestic fossil energy resources. In order to ensure these limited research dollars are spent wisely, we must focus funding toward projects that are truly cutting edge, applying DOE's supercomputers, their light sources, and expertise toward developing next-generation materials while maximizing efficiencies.

The complex fossil energy research challenges we face today will require an all hands-on-deck approach. Academia, industry, and the DOE are the ideal partners to develop these solutions. I look forward to hearing about these great partnerships from our witnesses today. I'm particularly interested to hear from Dr. Erik Webb, who joins us from Sandia National Lab—welcome, Doctor—about how the DOE labs can take a leading role in this effort.

I want to thank all the witnesses in advance for testifying today and, Mr. Chairman, you for holding the hearing, and I yield back.

[The prepared statement of Mr. Weber follows:]

Thank you, Chairman Lamb, for hosting this hearing. Today, we will have the opportunity to hear about exciting new research and development in fossil energy.

Last year in the United States, coal and natural gas comprised 64% of net electricity generation, with that number expected to only dip to 58% by 2040. The use of fossil fuels in the power sector isn't going anywhere. We have incredible domestic fossil energy resources, and our economic stability depends on the power they produce.

So it's no surprise that we have a robust industry here at home investing in developing the next generation of technologies to produce and use American fossil fuels more efficiently, more safely, and at a lower cost for American consumers.

Today's hearing is an opportunity for private sector organizations and DOE national labs to highlight their leading roles in fossil energy innovation. The scope and range of technologies being pursued is as vast as the untapped oil and gas reserves in Texas!

We'll hear from expert witnesses about research in materials science that can prevent CO_2 leaks in storage formations under high temperatures, pressures, and chemical conditions. I'm also excited to hear about a joint project between the Nuclear and Fossil Offices at DOE that uses supercritical carbon dioxide as the working fluid, rather than steam, to dramatically increase energy conversion efficiency at 1/10th the cost.

While there are significant opportunities for worthy and exciting research in this field, it's our job in Congress to focus federal agencies on the best use of federal funds.

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The complex fossil energy research challenges we face today will require an all hands-on deck approach. Academia, industry, and the Department of Energy are the ideal partners to develop these solutions. I look forward to hearing about these partnerships from our witnesses today.

I'm particularly interested to hear from Dr. Erik Webb - who joins us from Sandia National Lab - about how the DOE labs can take a leading role in this effort.

I want to thank our all witnesses for testifying today, and the Chairman for holding this hearing.

Chairman LAMB. Thank you.

I now recognize Chairwoman Johnson for an opening statement.

Chairwoman JOHNSON. Thank you very much, Mr. Chairman, and good afternoon to everyone.

I do appreciate this hearing being held on the Department of Energy's efforts to mitigate the environmental impacts of fossil fuels used in the power sector, as well as in manufacturing processes.

Historically, fossil fuels have served as a primary source of U.S. energy as they provide reliable power at low cost. My home State of Texas has played an important role in the fossil fuels industry as the leading producer of crude oil and natural gas in the United States. However, as our Nation's priorities have evolved, we are now focused not only on using energy resources that provide low cost, dispatchable energy, but also ensuring that these are clean sources of energy.

That's why we must strengthen our investments in the Department of Energy's Office of Fossil Energy, which supports research to address the environmental impacts of fossil fuels. This includes the development of technologies such as carbon capture, carbon storage, and methane leak detection and mitigation.

Last Congress, I was proud to support the bipartisan *Fossil Fuel Research and Development Act of 2018*, which reauthorizes and expands these important research activities. I look forward to discussing our proposed updates to that legislation during today's hearing.

While fossil fuels play an important role in power generation, they are also an important resource for the manufacturing sector, which is responsible for the third highest level of carbon emissions economywide. Manufacturers rely on the combustion of fossil fuels

to provide high-temperature heat needed for a variety of processes, including the production of cement and glass.

Technologies already being developed, like carbon capture, will play an important role in reducing industrial emissions, but we need to develop a variety of technologies that reflect the diversity of our Nation's manufacturing sector, from traditional sectors like the automobile manufacturing, to more innovative sectors like sustainable building materials.

That is why I am pleased that this hearing will also consider another proposed bill today, the *Industrial Decarbonization Technology Development Act of 2019*, which would authorize a cross-agency research initiative led by the Department of Energy to reduce emissions from long-distance transportation and manufacturing. Investing in research to reduce emissions from these important economic sectors is essential to meeting our climate change mitigation goals.

I'm looking forward to hearing from our distinguished group of witnesses today on the research investments we need to make to make the transition toward a clean energy economy. I thank you for being here today, and with that, I yield back.

[The prepared statement of Chairwoman Johnson follows:]

Good afternoon and thank you, Chairman Lamb, for holding today's hearing on the Department of Energy's efforts to mitigate the environmental impacts of fossil fuels used in the power sector as well as in manufacturing processes.

Historically, fossil fuels have served as the primary sources of U.S. energy as they provide reliable power at low costs. My home state of Texas has played an important role in the fossil fuel industry as the leading producer of crude oil and natural gas in the U.S. However, as our nation's priorities have evolved, we are now focused not only on using energy sources that provide low cost, dispatchable energy, but also ensuring that these are clean sources of energy.

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I am looking forward to hearing from our distinguished group of witnesses today on the research investments we need to make to make the transition towards a clean energy economy. Thank you for being here today.

With that, I yield back.

Chairman LAMB. The Chair now recognizes Ranking Member Lucas for an opening statement.

Mr. LUCAS. Thank you, Chairman Lamb, for hosting this hearing, which is especially relevant to the natural gas industry in my own Oklahoma district.

Fossil fuels provide over 80 percent of energy worldwide and remain the dominant source of energy here in the U.S. Petroleum, natural gas, and coal provided more than 80 percent of total U.S. energy consumption for the past 100 years, with energy reserves to power our Nation for the next century.

In order to responsibly use our vast energy resources, the next generation of fossil fuel technologies must be more efficient, cleaner, and less expensive for American consumers. Fortunately, our country is uniquely positioned to prioritize the basic and early-stage research that leads to groundbreaking technology.

In the 3 years since the U.S. began exporting liquefied natural gas, we've become the world's third largest supplier. The U.S. is projected to double export capacity by the end of 2020 and become the top exporter by 2025. This is an incredible achievement made possible by American science and technology. Federally funded research programs have a history of paving the way for industry innovation. DOE labs created the drill bit technology that led to hydraulic fracturing and horizontal drilling, revolutionizing the oil and gas sector.

Basic research in geology at the Department of Energy's Sandia National Lab led to the development of microseismic fracture mapping techniques for hydraulic fracking. And sensor technologies originally developed for aerospace applications at NASA and the Department of Defense have been used to improve safety in oil and gas development. In all these cases, industry partners adopted techniques developed in the laboratory for commercial use, maximizing energy production across the country. Today, DOE contributes to make key investments in early-stage fossil energy research, while the private sector takes the lead on efforts to deploy new technologies.

Innovators in our national labs are building on decades of groundbreaking successes in oil and gas production. I'm particularly interested to hear from Dr. Erik Webb on how Sandia National Lab is using monitoring systems and mathematical models to better understand the subsurface. His research will help fossil energy producers make more informed decisions before they drill a well, saving time, money, and reducing their environmental footprint along the way.

We know that industry has the resources, the capital, and the capacity to successfully commercialize new technology. What they often don't have is the infrastructure to conduct early-stage research and maintain historical data. This is where DOE, national labs, and academia can help.

At the National Energy Technologies Laboratory, the Nation's leading fossil fuel lab, researchers are speeding up the process of high-performance computing. Using the laboratory's Joule 2.0 supercomputer, which recently received a $16.5 million upgrade that boosted this computing power by roughly 8 times. DOE researchers have helped industry optimize chemical reactor designs and measure and improve the efficiency of gas turbines.

With DOE's research, industry can improve the next generation of power plants, using computerizational models to save time and money in planning and producing power more efficiently with less impact on the environment. The Department plays an important role in ensuring energy producers are utilizing the most efficient, safe, and clean technologies. We in Congress owe it to the American consumers to prioritize this important research and responsibly provide the needed energy for economic development, while maintaining environmental stewardship.

I want to thank you, Chairman Lamb, for holding this hearing, and I look forward to hearing from the witnesses today about the path forward for our next generation of fossil fuel technology.

I yield back, Mr. Chairman.

[The prepared statement of Mr. Lucas follows:]

Thank you, Chairman Lamb, for hosting this hearing which is especially relevant to the natural gas industry in my Oklahoma district.

Fossil fuels provide over 80% of energy worldwide and remain the dominant source of energy here in the U.S. Petroleum, natural gas, and coal provided more than 80% of total U.S. energy consumption for the past 100 years, with energy reserves to power our nation for the next century.

In order to responsibly use our vast energy resources, the next generation of fossil energy technologies must be more efficient, cleaner, and less expensive for American consumers. Fortunately, our country is uniquely positioned to prioritize the basic and early-stage research that leads to groundbreaking technology.

Federally funded research programs have a history of paving the way for industry innovation. DOE labs created the drill bit technology that led to hydraulic fracturing and horizontal drilling, revolutionizing the oil and gas sector.

Basic research in geology at the Department of Energy's Sandia National Lab led to the development of microseismic fracture mapping techniques for hydraulic fracturing. And sensor technologies originally developed for aerospace applications at NASA and the Department of Defense have been used to improve safety in oil and gas development.

In all of these cases, industry partners adapted techniques developed in the laboratory for commercial use, maximizing energy production across the country.

Today, DOE continues to make key investments in early-stage fossil energy research, while the private sector takes the lead on efforts to deploy new technologies. Innovators in our national labs are building on decades of groundbreaking successes in oil and gas production.

I am particularly interested to hear from Dr. Erik Webb on how Sandia National Lab is using monitoring systems and mathematical models to better understand the subsurface. His research could help fossil energy producers make more informed decisions before they drill a well - saving time, money, and reducing their environmental footprint along the way.

We know that industry has the resources, capital, and capability to successfully commercialize new technology. What they often don't have is the infrastructure to conduct early-stage research and maintain historical data. This is where DOE, national labs, and academia can help.

At the National Energy Technologies Laboratory (NETL), the nation's leading fossil energy lab, researchers are speeding up this process with high performance computing. Using the lab's Joule 2.0 supercomputer - which recently received a $16.5 million upgrade that boosted its computational power by roughly eight times - DOE researchers are helping industry optimize chemical reactor designs and measure and improve the efficiency of gas turbines.

With DOE's research, industry can improve the next generation of power plants, using computational designs to save time and money in planning, and producing power more efficiently with less impact on the environment.

The Department plays an important role in ensuring energy producers are utilizing the most efficient, safe, and clean technologies. We in Congress owe it to American consumers to prioritize this important research, and responsibly provide the needed energy for economic development while maintaining environmental stewardship.

I want to thank you Chairman Lamb for holding this hearing, and I look forward to hearing from our witnesses today about the path forward for next generation fossil energy technology.

Chairman LAMB. Thank you.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

Now, I'd like to introduce our witnesses. Ms. Shannon Angielski is a Principal at Van Ness Feldman, LLP, a Washington, D.C.-based law firm that specializes in energy environment and national resource policy and law. She serves as Executive Director of the Carbon Utilization Research Council (CURC), which is a coalition of electric utilities that rely on coal and natural gas for electricity production, gas distributors, equipment manufacturers, national associations, State universities, and technology research organizations. CURC's stated mission is to advance technology systems solutions for the responsible use of our fossil energy resources in a balanced portfolio to support our Nation's need for reliable and affordable energy.

Mr. Elgie Holstein is the Senior Director for Strategic Planning at the Environmental Defense Fund (EDF) in Washington, D.C. Prior to joining EDF in 2009, he was Co-Director of the DOE Presidential transition team and has held numerous senior positions in government, including the role of Associate Director for Natural Resources, Energy, and Science in the Office of Management and Budget; Special Assistant to the President for Economic Policy at the National Economic Council; and Chief of Staff for the U.S. Department of Energy under President Clinton.

Mr. Jeff Bobeck is the Director of Energy Policy Engagement at the Center for Climate and Energy Solutions. Mr. Bobeck leads the work of C2ES in co-convening the National Carbon Capture Coalition, which includes executives from energy, industrial and technology companies, labor unions, environmental and energy policy organizations. The coalition's stated mission is to simultaneously foster domestic energy production, support jobs, and reduce emissions. Spoken like a western Pennsylvanian because I believe he is one. Prior to his current position, Mr. Bobeck served as Director of Communications and External Affairs for the U.S. Department of Energy under President George W. Bush, held senior positions with the American Automobile Manufacturers Association, and the Global CCS Institute.

Ms. Erin Burns is the Director of Policy at Carbon180, a nongovernmental organization focused on carbon removal where she works with scientists, entrepreneurs, academics, and policymakers to create and inform Federal policy on carbon capture, removal, and use. Prior to her current position, Ms. Burns served on the staff of Senator Manchin where she handled energy, environmental, labor, and agricultural issues and worked as a Senior Policy Advisor for Third Way, a D.C.-based think tank managing its carbon capture and removal innovation and other clean energy policy issue areas.

And last but certainly not least, Dr. Erik Webb is the Senior Manager of the Geoscience Research and Applications Group at Sandia National Laboratories. Prior to his current position, Dr. Webb managed Sandia's Global Security Systems and Technologies Department, leading the second line of defense program responsible for creating a nuclear detection network at international ports of

entry in 50 countries. He also served on the staff of former Senator Domenici focusing on energy and water policy issues and is a fellow on the Senate Energy and Natural Resources Committee. Dr. Webb has a Ph.D. in hydrology with an emphasis in modeling and applied math from the University of Wisconsin.

As our witnesses should know, you will each have 5 minutes for your spoken testimony. Your written testimony will be included in the record of this hearing. And when you have all completed your spoken testimony, we will begin with questions. Each Member will have 5 minutes to question the panel.

And we will start with Ms. Shannon Angielski. And I apologize if I pronounced that wrong. You can correct us so the rest of us don't do that.

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

Ms. ANGIELSKI. No, I'm actually very impressed. Thank you. I think this is the first time that anybody has actually pronounced my last name the right way, so you must come from Pennsylvania coal country——

Chairman LAMB. There you go.

Ms. ANGIELSKI [continuing]. Because that's where my name comes from.

So let me just say thank you, Chairman Lamb, Ranking Member Weber, and to the Members of the Subcommittee for the invitation to testify and do so in support of the *Fossil Energy Research and Development Act of 2019*.

As Chairman Lamb has already pointed out, the CURC is an industry coalition that's really focused on technology solutions for fossil utilization, fossil energy utilization. What's important about our group is that members of CURC believe that American fossil fuels and ingenuity and technology innovation will satisfy our world's growing appetite for affordable energy, improve our energy security, increase exports, create high-paying jobs, and improve environmental quality.

In order to meet these important objectives, members of CURC are at the forefront of their organizations and partnering with the Department of Energy to develop and commercialize technologies that will transform the way that we use our fossil fuels. Successfully achieving these objectives will require a strong public-private partnership with the Federal Government providing strategic investments in the research development and demonstration that's needed, and that's why we are here to support the bill that is before this Committee.

Consumption of fossil fuels, as you pointed out, Mr. Chairman, it's on the rise both internationally, as well as domestically, but I think the international aspect of this is really important to focus on. It's because it's due to the role the fossil fuels play in providing affordable, accessible, and reliable energy.

According to the International Energy Agency and the United Nation's Intergovernmental Panel on Climate Change, carbon capture utilization and storage or CCUS as we call it, it will be a critical component of the portfolio of energy technologies needed to re-

duce carbon dioxide emissions worldwide. And the good news is that the U.S. has been the leader in the development of this technology with the support of the Department of Energy's world-class carbon capture and storage programs.

By way of example, DOE supported the Nation's first commercial-scale carbon capture demonstration project that is successfully operating on a coal-fired power plant in Texas. That's the Petra Nova project. And it's—as the U.S. continues to invest in these types of projects and in the research that's needed will benefit not only from cleaner power but also from new markets for U.S. technologies both domestically and abroad.

I want to point out that Congress actually made a critical step last year in catalyzing a CCUS industry in the U.S. due to the enactment of the *FUTURE Act*, and this would extend and expand the section 45Q carbon sequestration tax credits. And they're already incentivizing CCUS projects across several industries.

However, today's CCUS technology is still at the early stages of deployment and thus relatively expensive to implement in some industries like the power sector, and that's why improved carbon capture technologies will be needed to help reduce those costs when implemented in commercial practice.

I like to think of it as like the wind and solar industry about 15 years ago actually. A combination of Federal incentives such as those tax credits, when combined with Federal funding for research and demonstration, it—that's what's going to be needed to improve the technologies so the cost of CCUS and carbon capture can be reduced and replicated in commercial practice. That's again why the draft bill that's the subject of today's hearing is really important to achieve that objective.

Members of our organization and the Electric Power Research Institute are constantly evaluating technology development needs that reflect the changing markets and policies that impact fossil fuel use in the power sector. And about every 3 years those technology assessments are communicated through the publication of something we call an Advanced Fossil Energy Technology Roadmap, which we published the most recent version of last summer.

And this Roadmap identifies pathways to accelerate the development of transformational coal and natural gas-generating options that include carbon capture. And the Roadmap identifies several transformational technologies that are also identified in the draft bill that can be available in the next 10 to 15 years, and that can also provide dispatchable, low-carbon power that's needed to support the growth of renewables on the grid.

These include novel fossil power cycles such as those that I believe Dr. Webb will refer to later through supercritical CO_2 cycles, and they also include processes or other technologies that are designed to facilitate the carbon—the capture of carbon at lower energy penalty and at cost than conventional methods that we have available to us today. These processes are inherently more efficient, resulting in fewer emissions and require less fossil fuel to be used to produce electricity.

There's also specific research identified in the roadmap that is necessary to support these new cycles, including advancements in turbine technologies, high-temperature materials that are nec-

essary to achieve those efficiencies. And their roadmap also outlines advances in carbon capture technologies that are 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. And again, all of these elements of our Roadmap recommendations are embodied in the draft legislation.

It's important to recognize that some of these technologies are ready for testing today at some scale or even at some commercial demonstration-scale projects, and that's why it's critical that Federal policies support not only research and development but also the piloting and demonstrating of these innovative first-of-a-kind technologies, without which they would not likely succeed in the commercial markets. And this means annual Federal budgets should increase in the next several years to support the scale-up of these efforts, as outlined in the draft bill.

It's also important to note that Congress ensure that new technologies that receive Federal funding through the research program and are demonstrated at facilities such as Petra Nova are not considered as a basis for regulating a federally mandated emissions standard. CURC very much supports the intent of Congress through the proviso included in the *Energy Policy Act of 2005*, which was enacted to alleviate private-sector risk with implementation of new early-stage technologies that are not yet economic or commercial. CURC urges Congress to maintain this proviso by adding it into the *Fossil Energy Research and Development Act of 2019*.

I want to conclude by sharing some of the analysis that's been conducted by the CURC in ClearPath with modeling provided by NERA Economic Consulting and Advanced Resources International that 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 that up to 87 gigawatts of market-driven carbon capture deployment, paired with enhanced oil recovery by 2040, could result in significant increase in domestic oil production, lower cost—and lower cost retail electricity rates, all of which contribute to substantial increases in annual GDP, as well as over 800,000 new jobs that are created by 2040. These macroeconomic benefits are described in more detail in my written testimony.

Let me just close by saying we are pleased to testify and happy to answer questions.

[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

Subcommittee on Energy

Hearing on "Fossil Energy Research: Enabling Our Clean Energy Future"

CURC Testimony:

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

Washington, D.C.

June 19, 2019

EXECUTIVE SUMMARY OF CURC TESTIMONY: KEY POINTS

CURC is an industry coalition focused on technology solutions for the responsible use of our fossil energy resources in a balanced, low carbon generation portfolio. CURC's members include many of the largest coal producers in the nation, electric utilities and power generators that rely upon coal and natural gas for electricity production, equipment manufacturers and technology innovators, national associations that represent the power generating industry, national labor unions, and state, university and technology research organizations. Members of CURC believe that American fossil fuels and ingenuity in technology innovation will satisfy the our world's growing appetite for affordable energy, improve our energy security, increase exports of U.S. resources and manufactured energy equipment, create high-paying jobs, and improve environmental quality. In order to meet these important objectives, members of CURC are at the forefront of their organizations and partnering with the Department of Energy to develop and commercialize technologies that will transform the way we use fossil fuels. Successfully achieving these objectives will require a strong public-private partnership with the federal government providing strategic investments in research, development and demonstration (RD&D).

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. According to the International Energy Agency and United Nations Intergovernmental Panel on Climate Change, carbon capture, utilization and storage ("CCUS") is a critical component of the portfolio of energy technologies needed to reduce carbon dioxide emissions worldwide. The U.S. has been a leader in the development of this technology with the support of the Department of Energy's ("DOE") world class carbon capture and storage programs. Through a federal grant, DOE supported the nation's first commercial-scale carbon capture demonstration project that is successfully operating on a coal-fired power plant in the U.S. – the Petra Nova project in Texas. As the U.S. continues to invest in CCUS, we will benefit not only from cleaner power, but also from new markets for U.S. technologies both domestically and abroad. Investment in carbon capture, utilization, and storage technologies will transform carbon dioxide into an economic resource, lower the cost of reducing emissions, create jobs, save consumers money, and safeguard our environment.

Congress made a critical step last year in catalyzing a CCUS industry in the U.S. through the enactment of the FUTURE Act to extend and expand the Section 45Q carbon sequestration tax credits. These credits are already incentivizing CCUS project across several industries. However, today's CCUS technology is still at the earliest stages of deployment and thus relatively expensive to implement in some industries like the power sector, and improved carbon capture technologies will be needed to reduce costs. Like the wind and solar industries that were just emerging 15 years ago, a combination of federal incentives such as tax credits and federal funding for research, development and demonstration will be needed to improve the technology so costs can be reduced. That is why the draft bill that is the subject of today's hearing is very important for an emerging CCUS industry, as it would authorize a new federal program for the U.S. Department of Energy to partner with the private sector in support of the research, development and demonstration activities necessary to accelerate commercial applications of carbon capture, storage, utilization and transformational, advanced power cycles. Such a program is necessary to compliment other federal and state policies that will enable a CCUS industry.

CURC members and the Electric Power Research Institute (EPRI) are constantly evaluating technology development needs that reflect the changing markets and policies that impact fossil fuel use. Every 2 to 3 years, those technology assessments are communicated through the publication of an Advanced Technology Roadmap. Last summer, CURC and EPRI published the *2018 Advanced Fossil Energy Technology Roadmap* which identifies pathways to accelerate the development of transformational coal and natural gas generating options that include carbon capture. The window for achieving transformational improvements in dispatchable generation is closing.

Over the next decade, over half of our existing coal and nuclear units will be candidates for retirement. According to EIA data, the average age of coal and nuclear fleet will be, on average, 60 years old in 2030. For power companies, the time to 2030 is a short time for new generation planning, which typically spans a period of 15 years. New, low emission baseload and dispatchable options that are cost competitive in the electricity market with other forms of low carbon technologies will be required to replace even just a portion of the dispatchable capacity necessary to maintain a diverse portfolio of electricity generation sources in the fleet of the future.

The good news is that there are several transformational technologies identified in the *Roadmap* that can serve as candidate, low carbon replacement options and still provide the dispatchable power needed to support the growth of renewables on the grid. 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. This means annual federal budgets should increase in the next several years to support the scale-up effort.

It is also important to note that Congress ensured that new technologies that receive funding through the federal RD&D program and are demonstrated at facilities such as PetraNova are not considered as a basis for regulating a federally mandated emissions standard. CURC very much supports the intent of Congress through the proviso included in the Energy Policy Act of 2005, which was enacted to alleviate private sector risk with implementation of new, early stage technologies that are not yet economic or commercial. CURC urges Congress to maintain this proviso by adding it to the Fossil Energy Research and Development Act of 2019.

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.

CURC is pleased to testify before the House Science, Space and Technology Committee in support of the draft bill, the "Fossil Energy Research and Development Act of 2019", as it embodies the technology recommendations of the *2018 Roadmap*. We look forward to working with the Members of this Committee as you advance the legislation and to incorporate additional language that will address the effect of implementation of new technologies funded through this program for purposes of setting emission standards.

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, low carbon generation portfolio. CURC's members include many of the largest coal producers in the nation, electric utilities and power generators 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. Members of CURC believe that American fossil fuels and ingenuity in technology innovation will satisfy the our world's growing appetite for affordable energy, improve our energy security, increase exports of U.S. resources and manufactured energy equipment, create high-paying jobs, and improve environmental quality. In order to meet these important objectives, members of CURC are at the forefront of their organizations and partnering with the Department of Energy to develop and commercialize technologies that will transform the way we use fossil fuels. Successfully achieving these objectives will require a strong public-private partnership with the federal government providing strategic investments in research, development and demonstration (RD&D).

We are pleased to testify before the House Science, Space & Technology Committee in support of a draft bill, the "Fossil Energy Research and Development Act of 2019", which would authorize a new federal program through the U.S. Department of Energy to partner with the private sector in support of the needed research, development and demonstration activities to accelerate commercial applications of carbon capture, storage, utilization and transformational, advanced power cycles that support the goals of the legislation.

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, and is the reason why we have fracking technology that has allowed our nation to unlock the potential from our vast natural gas resources.

Technology for the use of our nation's coal and fossil fuels is important, as these resources are growing in the global and domestic energy economy. Domestically, coal and natural gas comprised 80% of total U.S. energy consumption[1] and 63.5% of net electricity generation[2] in 2018. The U.S. Energy Information Administration (EIA) estimates that coal and natural gas will provide 58% of total U.S. net electricity generation in 2040[3] (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).

[1] EIA Today in Energy, April 16, 2019. https://www.eia.gov/todayinenergy/detail.php?id=39092
[2] EIA FAQ, Updated March 1, 2019. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3
[3] EIA 2019 Annual Energy Outlook. https://www.eia.gov/outlooks/aeo/pdf/appa.pdf

Figure 1 - U.S. and World Energy Consumption[4]

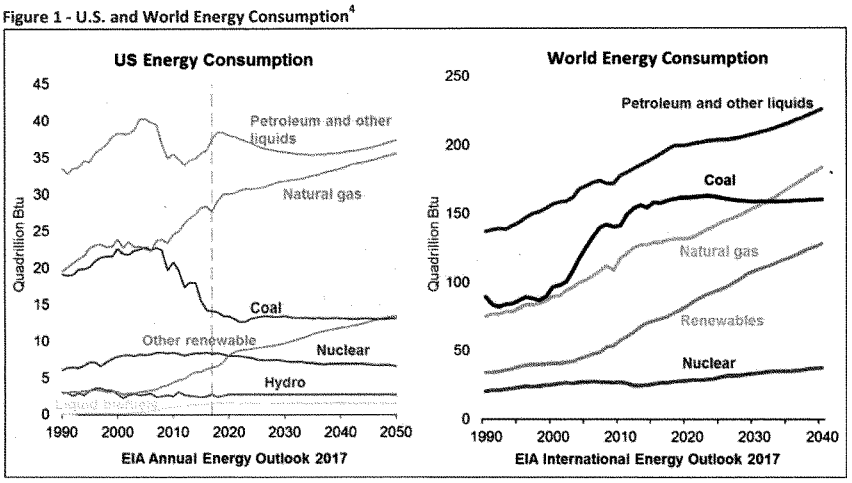
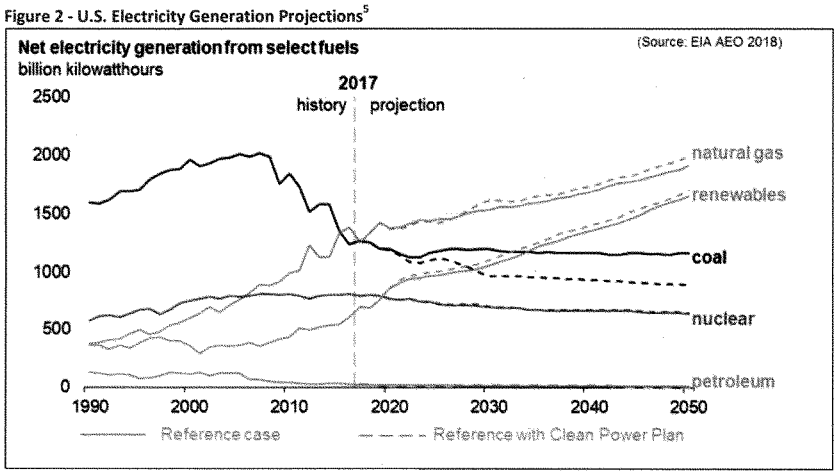


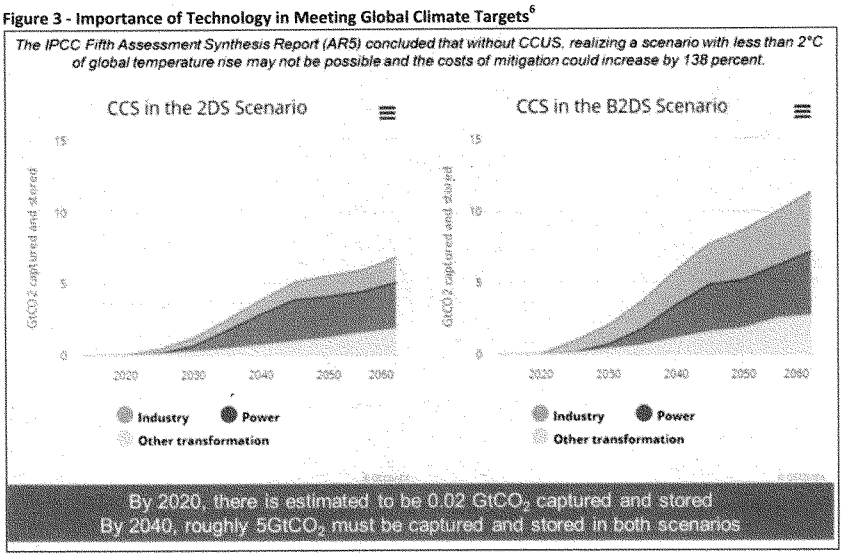
Figure 2 - U.S. Electricity Generation Projections[5]



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 growing use of fossil fuels. Several international models show the need for CCUS technology that significantly reduce carbon dioxide (CO_2) emissions to meet global climate targets (see Figure 3).

[4] EIA Annual Energy Outlook 2017, EIA International Energy Outlook 2017.
[5] U.S. EIA Annual Energy Outlook 2018.

Figure 3 - Importance of Technology in Meeting Global Climate Targets[6]



The U.S. has been a leader in the development of CCUS technology with the support of the Department of Energy's ("DOE") world class carbon capture and storage programs. Through a federal grant, DOE supported the nation's first commercial-scale carbon capture demonstration project that is successfully operating on a coal-fired power plant in the U.S. – the Petra Nova project in Texas. As the U.S. continues to invest in CCUS, we will benefit not only from cleaner power, but also from new markets for U.S. technologies abroad. Investment in carbon capture and utilization technologies will transform carbon dioxide into an economic resource, lower the cost of reducing emissions, create jobs, save consumers money, and safeguard our environment.

Congress made a critical step last year in catalyzing a CCUS industry in the U.S. through the enactment of the FUTURE Act to extend and expand the Section 45Q carbon sequestration tax credits. These credits are already incentivizing CCUS project across several industries. However, today's CCUS technology is still relatively expensive to implement in some industries like the power sector, and improved carbon capture technologies will be needed to reduce costs and transform the way we convert our fossil fuels to electricity in order to be cost-competitive with other low carbon generating options. Like the wind and solar industries that were just emerging 15 years ago, a combination of federal incentives such as tax credits and federal funding for research, development and demonstration, will be needed to improve the technology so that it can be cost-competitive with other forms of low CO_2 emitting technologies.

That is why the draft bill that is the subject of today's hearing is very important for an emerging CCUS industry, as it would authorize a new federal program for the U.S. Department of Energy to partner with the private sector in support of the research, development and demonstration activities necessary to accelerate commercial applications of carbon capture, storage, utilization and transformational, advanced power cycles. Such a program is necessary to compliment other federal and state policies that will enable a CCUS industry.

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[6] U.S. International Energy Agency, Carbon Capture and Storage, http://www.iea.org/topics/carbon-capture-and-storage/

It is also important to note that Congress ensured that new technologies that receive funding through the federal RD&D program and are demonstrated at facilities such as PetraNova are not considered as a basis for regulating a federally mandated emissions standard. CURC very much supports the intent of Congress through the proviso included in the Energy Policy Act of 2005, which was enacted to alleviate private sector risk with implementation of new, early stage technologies that are not yet economic or commercial. CURC urges Congress to maintain this proviso by adding it to the Fossil Energy Research and Development Act of 2019.

CURC members and the Electric Power Research Institute (EPRI) are constantly evaluating technology development needs that reflect the changing markets and policies that impact fossil fuel use. Every 2 to 3 years, those technology assessments are communicated through the publication of an Advanced Technology Roadmap. As an independent, nonprofit organization for public interest energy and environmental research, EPRI focuses 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.

Last summer, CURC and EPRI published the *2018 Advanced Fossil Energy Technology Roadmap* which identifies pathways to accelerate the development of advanced coal and natural gas generating options, as the window for achieving transformational improvements in dispatchable generation is closing. Over the next decade, a significant amount of coal and nuclear generation will be candidates for retirement. According to EIA data, the average age of coal and nuclear fleet will be, on average, 60 years of age in 2030. For power companies, this is a short time period for new generation planning, which typically spans a period of 10 to 15 years. That timeframe assumes existing units will not retire early due to economics or other market conditions that have led to recent premature retirements of coal and nuclear facilities. New, low emission technologies that are cost competitive in the electricity market will be required to supply the replacement baseload capacity necessary to maintain a diverse portfolio of electricity generation sources in the fleet of the future

This is the fifth Roadmap that CURC and EPRI have published since 2003. The 2018 Roadmap is a departure from prior Roadmaps published by CURC and EPRI as it includes new data on recent advances in technology for not just coal, but also natural gas in electric power generation. 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.

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.

SUMMARY OF CURC-EPRI ROADMAP FINDINGS

The technology pathways outlined in the *2018 Roadmap* will deliver cost-competitive and low or near-zero CO_2 emissions generation technologies that also mitigate the environmental footprint of using fossil fuels through reduced water consumption and other air emissions. Our analysis determined that many technologies are applicable to 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.

Several technologies identified in the *2018 Roadmap* will generate a new learning curve and result in new approaches for power generation and/or carbon capture to 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 *2018 Roadmap* identifies the cost and performance targets and the technology development necessary to bring each technology to commercialization will hitting those targets. The development needs and funding requirements for each technology are rolled up into an overall technology development timeline and funding schedule. The *2018 Roadmap* identifies a level of RD&D to ensure timely solutions are developed and pursued through aggressive public-private partnerships.

Example transformational technologies identified in the *Roadmap* include pressurized oxy-combustion, chemical looping combustion, 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, are 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 development needs for a range of technologies applicable to both coal- and natural gas-firing units. Cross-cutting technology priorities identified in the *Roadmap* include development of high-efficiency materials development, carbon capture, carbon utilization, carbon storage, turbines, water management technologies, and sensors and controls to improve diagnostic and predictive capabilities.

Materials development can be leveraged across a suite of technologies. Advanced Ultra-supercritical (A-USC) materials enable Rankine cycles with steam temperatures of 700°C or higher and are also needed for 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.

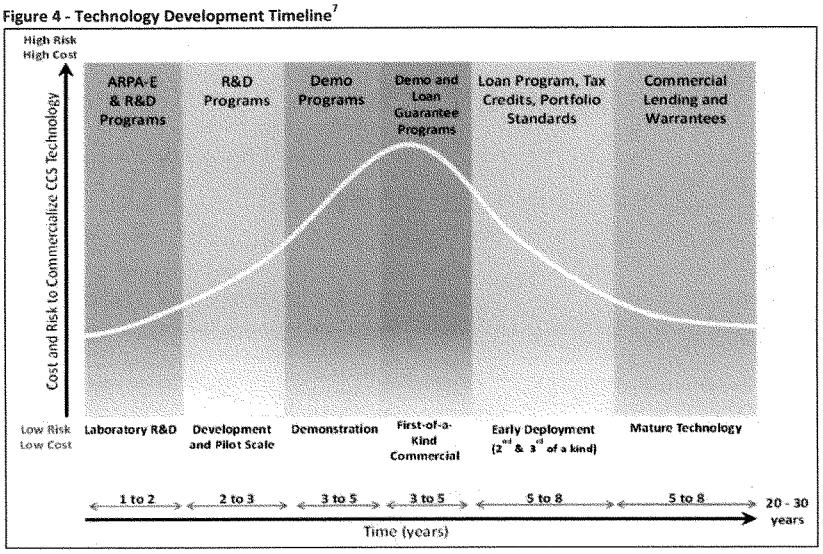
Once we capture CO_2, we must find a way to permanently sequester it. The Roadmap outlines a program for CO_2 utilization and storage, which is an important effort to evaluate geologic CO_2 storage reservoirs, necessary to ensure there will be readily accessible storage facilities for CO_2 produced from the advanced power systems under development. The *Roadmap* includes a program to advance technologies in this area. The Regional Carbon Sequestration Partnerships ("RCSPs") and the CarbonSAFE Initiative are necessary for industry to advance technologies that will help grow our economy and increase our energy independence through the utilization of CO2, and for which low-cost, industrial sources of CO2 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 (see Figure 4 which graphically depicts the timeline for different phases of development of energy technologies).

Figure 4 - Technology Development Timeline[7]



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.

That is why federal support for the RD&D efforts outlined in the Roadmap is critical, as several of those are readying for large-scale pilot testing and a few are preparing for commercial demonstration. It is critical that a program for piloting and demonstrating these technologies be implemented for these technologies to be successfully commercialized. This means annual federal budgets must increase in the next several years to support the scale-up effort.

PROJECTED BENEFITS OF THE ROADMAP

[7] CURC adaptation from EPRI TAG.

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

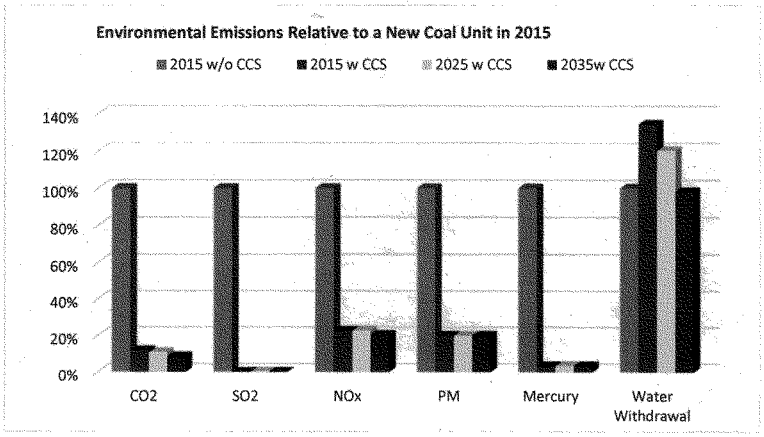
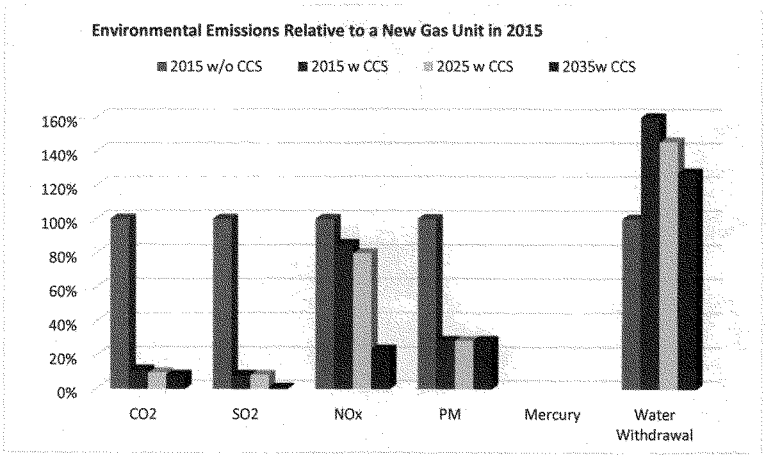


Figure 6 - Emissions Reductions from a new Gas Unit Projected in the CURC-EPRI Roadmap



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

Concurrent with the release of the *2018 Roadmap*, CURC and the ClearPath Foundation published 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 *2018 Roadmap*.[8] The study estimates that if an aggressive RD&D program is implemented that achieves the projected *Roadmap* 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:

[8] 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 CURC and EPRI published their *2015 Roadmap*, we have witnessed growing support for policies that favor CCUS and the technology recommendations that achieve the overall *Roadmap* objectives, including a program for large-scale pilots. In FY 2017, Congress appropriated $50 million DOE to undertake a new, transformational coal pilot program, and has since appropriated an additional $60 million for the program (for a total of $110 million). The intent of the program solicitation is to design, construct and operate two large-scale pilots with transformational attributes. 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.[9] The program is being carried out in three phases, and CURC has recommended that the Congress provide an additional $25 million in FY 2020 to move into Phase 3 of the program.[10]

Previous energy legislation has included recommendations from prior *CURC-EPRI Roadmaps*, including the provisions of the Energy Policy Act of 2005, the Emergency Economic Stabilization Act of 2008, and more recently, comprehensive legislation that passed in the Senate but ultimately was not enacted at the end of the 114th Congress. In the 115th Congress, the first iteration of this Committee's Fossil Energy Research and Development Act (H.R. 5745) included provisions reflecting the recommendations of the *2018 Roadmap*. Similarly, legislation introduced last Congress by Senator Joe Manchin (D-WV), the Fossil Energy Utilization and Leadership (FUEL) Act (S. 2803), incorporated *CURC-EPRI Roadmap* recommendations.

In this Congress, Senator Manchin introduced the Enhancing Fossil Fuel Energy Carbon Technology (EFFECT) Act (S. 1201). That legislation builds on the FUEL Act and continues to incorporate recommended technology development pathways identified in the *2018 CURC-EPRI Roadmap*. The bill has bipartisan support and is cosponsored by Senator Lisa Murkowski (R-AK), Chairman of the Senate Energy and Natural Resources Committee, and would serve as a companion to the draft bill that this Committee has developed. CURC is appreciative of the Committee's leadership to reintroduce Fossil Energy Research and Development Act as it also continues to incorporate *CURC-EPRI Roadmap* recommendations that are critical to the development and deployment of the technology.

Lastly, 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 is pleased to support of the draft bill, the "Fossil Energy Research and Development Act of 2019", as it embodies the technology recommendations of the *2018 Roadmap*. We look forward to working with the Members of this Committee as you advance the legislation and to incorporate language that will address the effect of implementation of new technologies funded through this program for purposes of setting emissions standards.

Thank you for the opportunity to provide this testimony.

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

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

APPENDIX

Table 1 - Technology Programs Supported in the 2018 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

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Executive Director, 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). CURC is a coalition of producers, electric utilities that rely upon coal and natural gas for electricity production, gas distributors, equipment manufacturers and technology innovators, national associations, and state, university and technology research organizations (see www.curc.net). Members of CURC coalesce around the need for technology solutions to ensure the responsible use of our fossil energy resources in a balanced, low carbon generation portfolio. They serve this mission by evaluating technology development needs, developing policies and public-private programs to advance technology solutions, and by advocating for the advancement of those policies with policymakers, NGOs and other stakeholders. Advancing carbon capture, utilization and storage is a key component of the policy portfolio that CURC serves.

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, and serves on the board of the Washington Coal Club.

Chairman LAMB. Thank you very much. Mr. Holstein.

TESTIMONY OF ELGIE HOLSTEIN,
SENIOR DIRECTOR FOR STRATEGIC PLANNING,
ENVIRONMENTAL DEFENSE FUND

Mr. HOLSTEIN. Thank you, Mr. Chairman.

The clean energy revolution is indeed underway. It is rapidly evolving into a global competition for market share in a world that is coming to understand how little time remains to avoid the disastrous impacts from climate change. As long as fossil fuels remain a part of our energy profile, we will need strategies to improve their environmental performance. The pace of global climate change is simply too fast, and the consequences of inaction too dire to do otherwise.

To fight climate change, American leadership is desperately needed at home and internationally. It is crucial for us to remember, however, that even as we invest in ways to reduce the environmental impacts of fossil fuels and develop and deploy noncarbon alternatives, we still need an overarching economic policy framework. That framework should provide enforceable, declining, and economy-wide limits on carbon emissions, all on a timetable that avoids the worst tipping points associated with unconstrained and rising greenhouse gas concentrations. That means achieving net zero global greenhouse gas emissions by 2050.

While we have not yet developed the bipartisan consensus needed to enact a carbon price and limit, an aggressive program to drive clean energy and climate innovation is within reach, and it's needed right now. Such an innovation portfolio will help build political confidence by accelerating the decline in the cost of emissions reductions.

America has the intellectual capital, the research infrastructure, the workforce, and the manufacturing prowess to solve our technology and climate challenges, and we do need to do it all. In the context of today's hearing and the draft bills you are considering, that means mounting ambitious research, development, demonstration, and commercialization efforts.

To be sure, there are some efforts and technology directions mentioned in the bills that may not prove out. That is, they may not reach the goals of cost-effective decarbonization and marketable, viable technology applications. The point is to find out. The point is to find out.

The draft *Fossil Energy R&D Act of 2019* wisely emphasizes the need for environmental integrity safeguards as part of any plan to develop and commercialize carbon management technologies. Such measures are needed to protect against haphazard and ineffective containment of CO_2. We strongly endorse such measures as a key element of any carbon reduction policy or program.

The draft Fossil Energy R&D bill also instructs DOE to undertake a research program to identify the best methods and to assess the state of technology for preventing and detecting methane emissions from the Nation's extensive natural gas infrastructure. Now, I think many Members of this Committee have heard me say in previous testimony that natural gas, as we know, is mostly methane, and when it leaks or is vented into the atmosphere, it is more

than 80 times as potent as CO_2 over the first 20 years following its release in terms of the damage it does to the climate. In fact, methane is responsible for about 25 percent of the global warming we are experiencing today. We welcome the methane provisions in the draft bill.

The *Industrial Decarbonization Technology Development Act* (IDTDA) tackles another aspect of controlling greenhouse gas emissions. The power sector has seen many innovations that hold the promise of decarbonizing and building resilience in our electricity sector, but other sectors, including buildings, process industries, shipping, aviation, and manufacturing have not experienced the same level of technology innovation and adoption.

That's why the IDTDA offers a promising new focus on opportunities to drive industrial decarbonization. Of particular value is the bill's creation of two new entities designed to leverage those capabilities. First, it creates an advisory committee to bring to the Department the best of government and private-sector expertise in developing needed new technologies.

Second, it helps the Department overcome an area of long-standing weakness: Translating technology development into commercial deployment. The clearinghouse function for best practices and technology should be seen not only as a way to accelerate emissions reductions but also as an ingredient of national industrial competitiveness. And I think the Members of this Committee have seen how ARPA-E (Advanced Research Projects Agency-Energy) has done precisely that—taken new technologies, helped to commercialize them, and get these industries moving forward so that America can have a competitive edge in global markets.

Taken together, these two draft bills represent a strong step in the direction of answering the key question about decarbonization: What works, and then getting solutions into the market.

Thank you for the opportunity to testify today, and I look forward to answering any questions you may have.

[The prepared statement of Mr. Holstein follows:]

EDF
ENVIRONMENTAL DEFENSE FUND
Finding the ways that work

Testimony of Elgie Holstein

Sr. Director for Strategic Planning, Environmental Defense Fund

Before the Subcommittee on Energy of the House Committee on Science, Space and Technology

June 19, 2019

Chairman Lamb, Ranking Member Weber, and Members of the Subcommittee:

Thank you for the opportunity to testify today. The clean energy revolution is underway. It is rapidly evolving into a global competition for market share in a world that is coming to understand how little time remains to avoid disastrous impacts from climate change.

But the imperative to reduce greenhouse gas emissions – and to do so quickly – is constrained by a variety of factors. Our fossil fuels-based legacy energy systems have a huge head start, with literally trillions of dollars worth of capital investment often backed by ongoing support from governments.

The costs of renewable electricity, energy efficiency, electric vehicles, and other emerging clean energy technologies have fallen steadily and will continue to do so. But even as the market continues to favor them over new coal-fired electricity generation, the existing fossil fuel and new gas-fired generating capacity, together with most of our transportation, industrial, and buildings sectors continue to require substantial quantities of fossil fuel-based energy inputs.

The result, unless we take strong action now, will be increasing levels of greenhouse gas pollution added to the dangerous concentrations already accumulated as a result of human activities – specifically, the burning of fossil fuels. In addition to greenhouse gases, other emissions from burning fossil fuels pose a continuing threat to the health of families and communities around the world.

Even as investments in, and deployments of, renewable energy, energy efficiency, electric vehicles, and other emerging clean energy technologies continue to grow, science is telling us that we need to move faster and more broadly to curb worldwide greenhouse gas emissions. The inescapable conclusion is that for as long as fossil fuels remain a part of our energy profile, we will need strategies to improve their environmental performance.

The pace of global climate change is simply too fast, and the consequences of inaction too dire, to do otherwise.

Still, even as we invest in ways to reduce the environmental impacts of make investments in cleaning up fossil fuels and in developing non-carbon alternatives, we still need the additional support of a clear policy framework that reflects the cost of carbon pollution and limits carbon emissions. That framework must be constructed on a timetable for emissions reductions sufficiently ambitious to ensure that we stay below a 2-degree Celsius increase from pre-

industrial levels in average global temperatures. In terms of a deadline, we need to achieve a net zero greenhouse gas emissions rate by 2050. Science tells us in no uncertain terms that temperature increases above the 2-degree threshold will lead to dangerous, potentially irreversible "tipping points."

Disruption and outright loss of agricultural capacity, coastal inundation, shifting and loss of fish stocks, spreading disease vectors, widespread species extinction, super-fires, and of course, catastrophic storms and changing weather patterns are, to varying extents, happening already. If we do not act decisively, those impacts will become commonplace and far more severe. They will cost more human lives – and a lot more money. They will destroy more communities, disrupt economies and ways of life, drive destabilizing land changes, set in motion mass human migrations, and present serious new national security challenges. Future generations will never forgive us if we allow that nightmare to become real.

To make sure it does not, we must act on all fronts. Such action should reflect both domestic and international opportunities for collaboration and outreach. It must also draw upon the enormous advantages we have in science, technology, economic strength, and our skilled and educated workforce.

To fight climate change, American leadership is desperately needed both at home and internationally. Withdrawing from the Paris Climate Accord, as the President has promised to do, is a mistake. So is restricting clean energy and climate-related funding for science agencies, researchers, and programs – including at the Department of Energy, NASA, NOAA, EPA and others.

This hearing, and most of my testimony, focuses on efforts to catalyze innovation through federally supported technology research, development, demonstration and commercialization -- including of technologies that remove carbon directly from the atmosphere. But it is crucial for us to remember that even as we invest in ways to reduce the environmental impacts of fossil fuels, and develop and deploy non-carbon alternatives, we need an overarching economic policy framework.

That framework should provide enforceable, declining, and economy-wide limits on carbon emissions, while providing flexible, market-based approaches to staying within them – all on a timetable that ensures that we avoid the worst tipping points associated with unconstrained and rising greenhouse gas concentrations. That means achieving net zero global greenhouse gas emissions by 2050. Such an economic framework would ensure several things:

First, it sends a definitive signal to all sectors of our economy about where we are headed: toward a clean and sustainable energy future. That signal will awaken the collective ambitions and skills of our entrepreneurial, dynamic economy. It will serve as a call to action for everyone from inventors to international investors, including profit-seekers, scientists, and yes, political leaders -- all chasing the opportunities to make a difference and to secure a place in the accelerated, purpose-driven clean energy revolution.

Second, it will mobilize America's vast scientific, technical, and manufacturing assets. Policy uncertainty has kept too many of those assets disengaged from the race to develop new clean energy-related technologies and to reduce the environmental harm from large-scale dependence on fossil fuels.

Third, it will stimulate corporate investment decisions, so that emissions reductions will become an important driver of R&D and capital equipment spending decisions.

Fourth, it will engender a surge in job creation as American workers produce and install the equipment needed to reduce emissions.

This economic policy framework, when paired with innovation programs, will result in deeper pollution reductions, accomplished more quickly and affordably. That's because a limit and price on emissions will accelerate demand for clean energy, creating powerful economic incentives to adopt new technologies and provide a market for innovators who develop better ways to cut carbon. Innovation programs can help make new technology options available – but in order to ensure that they will be adopted on the timeline needed to meet climate goals, we also need policies that create a level playing field that allows clean technologies to thrive.

The political will to establish carbon limits has emerged in a number of new states, including Virginia, Oregon, and Colorado. And for years, California – the largest economy among the states, (and the 5th largest in the world if it were a nation) – has been reducing its emissions ahead of schedule and at lower costs than predicted using a flexible market-based approach with declining limits on pollution. This has also been the case in regional markets, such as the Regional Greenhouse Gas Initiative (RGGI) which focuses on reducing emissions in the electricity sector.

In just the latest vote of confidence in such market-based approaches, New Jersey has just this week re-enlisted in RGGI's now-10-state collaboration to reduce greenhouse gas emissions from the electricity sector. In the U.S. and around the world, these types of flexible, market-based programs that establish limits on pollution continue to drive emissions reductions faster and more cheaply than originally expected.

While we may not yet have the bipartisan consensus needed to enact a carbon price and limit, an aggressive program to drive clean energy and climate innovation is achievable. Such an innovation portfolio will help build political confidence by accelerating the decline in the cost of emissions reductions. Happily, many Members of Congress on both sides of the aisle are coming to recognize that American industrial innovation aimed at averting climate change disaster will yield enormous economic benefits in terms of job creation, export opportunities, industrial competitiveness and more. They realize that such investments are good not only for the climate but for the health of our families and our economy as well.

That emerging consensus is reflected in the House version of the FY20 Energy and Water appropriations bill on the floor this week. The bill soundly rejects the President's recommendations to cut deeply or eliminate funding for renewable energy development, building and industrial energy efficiency programs, and for innovative financing and investment programs, including those at ARPA-E. Instead, the bill provides major funding increases across a variety of clean energy and efficiency programs.

Fighting and winning a campaign to prevent the worst impacts of climate change from occurring means we must use every tool at our disposal, and resolve to invent new ones as we go forward.

In making judgements about the pace and scope of government's innovation investments, we must always be cognizant that we have little time to avert widespread ecological and economic

disaster. But we must also have the confidence that America has the intellectual capital, the research infrastructure, the workforce, and the manufacturing prowess to solve our technology challenges. And we know that markets can be successfully harnessed to leverage and incentivize public and private investments in emissions-reducing technologies.

We do need to "do it all." In the context of today's hearing and the draft bills you are considering, that means mounting ambitious research, development, demonstration, and commercialization efforts aimed at those technologies that:

a) have the potential for delivering significant greenhouse gas emissions reductions in the near- and mid-term;

b) are targeted at sectors, industries, products and processes that are particularly difficult to de-carbonize using current technology and under current market conditions;

c) have a viable pathway to commercialization, especially under market conditions where strong policies are in place that reflect the real cost of those emissions;

d) hold the promise of developing both domestic and export market opportunities while opening up new job opportunities for American workers.

The bills under consideration today reflect those criteria. To be sure, there are some efforts and technology directions mentioned in the drafts that may not prove out. That is, they may not reach the goals of cost-effective de-carbonization and marketable, viable technology applications. The point is to find out. And these bills help do that. These bills provide clear direction to the Department of Energy, accompanied by significant funding authorizations, to develop roadmaps for determining how we can best enable major reductions in fossil fuel-related emissions.

The draft Fossil Energy R&D Act of 2019 provides funding in the form of grants and prizes to those with the technical skills, experience, and entrepreneurial drive to discover what works in carbon capture, storage, utilization, and removal. The bill wisely emphasizes the need for environmental integrity safeguards as part of any plan to develop and commercialize carbon management technologies. Such measures are needed to protect our successes in de-carbonizing fossil fuels from being compromised by haphazard and ineffective containment. We strongly endorse such measures as a key element of any carbon-reduction policy or program.

The draft Fossil Energy R&D bill also instructs the Department of Energy to undertake a research program to identify the best methods, and to assess the state of technology, for preventing and detecting methane emissions from the nation's extensive natural gas infrastructure.

I have previously testified before members of this subcommittee regarding how important it is to control methane emissions, and the bill will help industry as well as state and federal policy-makers and regulators to forge solutions.

Natural gas is mostly methane, and when it leaks or is vented into the atmosphere, it is more than 80 times as potent as CO2 over the first twenty years following its release, in terms of the damage it does to the climate. In fact, methane is responsible for about 25% of the climate change we are experiencing today. At Environmental Defense Fund, we have been studying

methane in the oil and gas sector for a number of years, along with numerous research partners from across industry and academia. We welcome the methane provisions in the draft bill.

The draft Industrial Decarbonization Technology Development Act (IDTA) tackles another aspect of our efforts to control greenhouse gas emissions. The power sector has seen many innovations that hold the promise of de-carbonizing and building resilience in our electricity sector, including cost-competitive solar and wind generation, grid management software and sensors, demand response, utility-scale storage, clean and linked micro-grids, etc. But other sectors, including buildings, process industries, shipping, aviation, and manufacturing, have not seen the same level of technology innovation and adoption.

That's why the IDTA offers a promising new focus on developing additional opportunities to drive industrial de-carbonization. The bill leverages existing DOE programs that have deep and longstanding professional experience with energy efficiency and manufacturing. Of particular value is the bill's creation of two new entities designed to leverage those capabilities. First, it creates an advisory committee to bring to the Department the best of government and private-sector expertise in developing needed new technologies.

Second, it helps the Department overcome an area of longstanding weakness: translating technology development into commercial deployment. The technical assistance provisions of the bill will help provide the outreach and connectivity with the private sector that is needed in order to maximize the de-carbonization opportunities that the Department is developing. The clearinghouse function for best practices and technology should be seen not only as a way to accelerate emissions reductions, but also as an ingredient of national industrial competitiveness.

Taken together, these two draft bills represent a strong step in the direction of answering the key question about de-carbonization: "What works?" -- and then getting solutions into the market.

Looked at more broadly, they help define the research, development, demonstration and commercialization elements of a critically needed de-carbonization agenda. As discussed above, that agenda also includes robust appropriations support for clean energy innovation.

Finally, in addition to ensuring progress toward a net-zero emissions goal by 2050, we also need a policy framework that drives emissions reductions now by setting declining limits on carbon pollution and helps achieve them by ensuring that the cost of that pollution is reflected in energy and climate markets.

Thank you for the opportunity to testify today, and I look forward to any questions you may have.

Note: Attached to this testimony is a set of principles EDF believes should be applied to any national innovation program designed to help cut greenhouse gas emissions to a tolerable level. Many of the principles are reflected in the draft bills before you, but they are useful in considering other parts of a national de-carbonization agenda as well.

EDF Clean Energy Innovation Principles

Innovation programs can play a critical role in meeting climate goals by driving the development and commercialization of new, high-impact, breakthrough emissions-reduction technologies; driving down the costs and accelerating the adoption of existing, emissions-reducing technologies; and attracting private investment. Important technology areas include "negative emissions technologies" that remove carbon from fossil fuel combustion and from the air; utility-scale energy storage; building and industrial process efficiency; and next-generation batteries, nuclear designs, electric vehicles, and grid equipment.

While investment in innovation and technology is necessary, it is not sufficient on its own to solve the climate challenge. It must be paired with policies that set a declining limit on greenhouse gas emissions that puts us on a path to reach net zero greenhouse gas pollution by 2050, and account for the real costs of this pollution through a meaningful and transparent price on carbon. A price and limit on emissions will accelerate demand for clean energy, creating powerful economic incentives to adopt new technologies and providing a market for innovators who develop better ways to cut carbon. Working together, strong policies that limit emissions paired with investment in innovation will result in deeper carbon reductions, accomplished more quickly and affordably.

In addition, national innovation policy should be consistent with the following principles:

- **Performance-based.** The most promising technologies should receive the most funding, with the most important metric of performance being potential tons of pollution reduced per dollar invested.

- **Diversified.** Federal investment in innovation should take a broad-based approach, encompassing a wide range of technologies that can reduce emissions in sectors throughout the economy.

- **Risk tolerant.** Government should provide high-risk early-stage investments in potential breakthrough technologies, considering both likelihood of success and possible impact.

- **Ambitious.** Dramatic transformation of our energy system demands – at a minimum – doubling overall investment, from clean technology and energy efficiency R&D to deployment, commercialization, and financing programs that can help overcome market barriers while lowering costs and improving performance of more mature technologies.

- **Strategic.** Policies should aim to leverage private capital as much as possible, and avoid duplicating or "crowding out" private investment.

- **Coordinated.** Coordination across government agencies and programs, including within DOE, is critical to ensure investments are streamlined and their impacts maximized.

- **Adaptive.** Programs should require robust data collection and performance tracking to evaluate effectiveness per dollar and improve performance over time.

- **Environmental integrity.** Robust monitoring and verification of emissions reductions is critical – including carbon that's captured and stored underground or used in products or processes. It's also important to ensure full life-cycle accounting of emissions impacts – for example, taking into account land use changes as a result of biofuels production. Policies should guard against negative environmental or health impacts and respect local and national environmental laws.

Elgie Holstein

Elgie Holstein is Senior Director for Strategic Planning at Environmental Defense Fund in Washington, DC. Prior to joining EDF in 2009, he was co-director of the DOE presidential transition team.

He has held a number of senior positions in government and the private sector with a focus on energy, natural resources, and environmental policy.

His government service includes:

- Associate Director for Natural Resources, Energy and Science in the Office of Management and Budget;
- Special Assistant to the President for Economic Policy at the National Economic Council;
- Deputy Undersecretary and Assistant Secretary at the National Oceanic and Atmospheric Administration; and
- Chief of Staff at the U.S. Department of Energy.

Mr. Holstein has served as a consultant to DOE, including serving on an advisory committee of Sandia National Laboratories. He also has been an advisor to local governments on water and energy matters.

Earlier, Mr. Holstein served as Energy and Environment Staff Director for the National Conference of State Legislatures, worked as a congressional staff member specializing in energy and environmental policy, and headed a national consumer financial education and advocacy group.

Chairman LAMB. Thank you. Mr. Bobeck.

TESTIMONY OF JEFF BOBECK,
DIRECTOR OF ENERGY POLICY ENGAGEMENT,
CENTER FOR CLIMATE AND ENERGY SOLUTIONS

Mr. BOBECK. I'm here representing the Center for Climate and Energy Solutions or C2ES. We're an independent, nonpartisan organization with a mission of advancing real-world solutions on climate-related policy. We convene the Business Environmental Leadership Council, a group of 34 industry-leading companies. We partner with the U.S. Conference of Mayors and, relevant to today's topics, we co-convened the Carbon Capture Coalition, which has grown to more than 60 participants.

C2ES considers carbon capture to be an essential component in the comprehensive response to climate change for two reasons. Despite the growth in renewables, we expect that some level of dispatchable emissions-abated fossil-powered generation will be needed for decades to come. Mr. Weber mentioned 64 percent. Well, we're not going to turn that off by 2030.

Second, the manufacturer of products like steel, cement, and methanol produce greenhouse gas emissions as part of their basic processes. Carbon capture provides promising pathways to address both issues.

The International Energy Agency repeatedly has concluded that approximately 12 to 15 percent of greenhouse gas emissions must come from carbon capture by 2050 if the 2-degree warming scenario is to be met. Moreover, IEA found that removing carbon capture from the emissions reduction toolbox would more than double the cost of keeping warming below 2 degrees. In the United States, the ongoing improvements in efficiency and cost of carbon capture owe much to the work of DOE's Fossil Energy R&D program and the work conducted by the National Energy Technology Laboratory or NETL.

Mr. Chairman, as you mentioned, I grew up in Pennsylvania's present-day 17th District, and I remember well our school field trip to what was then called the U.S. Experimental Mine. That facility became a national laboratory in 1999 and now, drawing on more than a century of history, NETL is the home of some of the most forward-looking energy research anywhere in the world.

However, the program still operates under its 2005 authorization, thus many of its current research objectives such as carbon utilization and direct air capture were not envisioned by Congress at that time. The *Fossil Energy Research and Development Act* brings the program's statutory direction into the modern era, providing updated program guidance while allowing for flexibility as priorities change and technologies develop. It would establish regional centers to address region-specific capture, storage, and utilization needs, and it would provide higher funding authorization levels, which a wide variety of stakeholders, including industry, labor, and NGOs, would support.

One area of research targeted by the bill I mentioned is carbon utilization, which C2ES believes holds great promise as a pathway for decarbonization, especially for industry. We will soon publish a new report on the subject detailing how utilization can be espe-

cially effective in addressing harder-to-decarbonize industrial sectors. The legislation before the Committee today could help to accelerate carbon utilization's development and deployment.

The second bill before the Committee today, the *Industrial Decarbonization Technology Development Act*, would elevate the issue of industrial emissions to provide better cross-agency coordination of policy. Because industrial challenges for steelmaking in Pennsylvania are different from those for chemical processing in Texas, the bill would also seek better intergovernmental cooperation and would require development of a national roadmap for decarbonization of difficult-to-decarbonize industries.

Allow me to close by saying a word about innovation. Innovation is not an end in itself but rather a means to deploying a more effective and economical greenhouse gas reduction. The seeds planted by federally supported innovation will not bear fruit without the enactment of other complementary policies without commensurate action at the local and State levels and certainly not without strong commitment by the private sector to shoulder some of the risk.

And we're behind. While nearly 40 million metric tons of carbon dioxide are currently stored or utilized annually around the world, the amount of carbon dioxide capture needs to grow by a factor of 100 by 2040 if carbon capture's necessary contribution to greenhouse gas reduction is to keep pace.

No proposed single policy reform offers a silver bullet, but rather a portfolio of policies is needed to address technology development, financing, and marketing preferences. But one thing at a time. We commend the Committee for proactively proposing thoughtful climate policies within its jurisdiction, and we look forward to working with you going forward. Thank you for your attention.

[The prepared statement of Mr. Bobeck follows:]

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

HEARING BEFORE THE

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

FOSSIL ENERGY RESEARCH: ENABLING OUR CLEAN ENERGY FUTURE

Testimony of

Jeffrey Bobeck, Director of Energy Policy Engagement at the
Center for Climate and Energy Solutions (C2ES)

Wednesday, June 19, 2019

Chairman Lamb, Ranking Member Weber, and members of the Committee, thank you for the opportunity to offer testimony today on proposed legislation aimed at strengthening the nation's foundation of research, development, and deployment of technologies to reduce greenhouse gas (GHG) emissions.

My name is Jeffrey Bobeck, and I am pleased to offer the views of the Center for Climate and Energy Solutions, or C2ES, on this issue and relevant proposed legislation. I serve as Director of Energy Policy Engagement at C2ES and previously was honored to serve as Director of the Office of Communications and External Affairs at the Department of Energy from 2006–2009.

C2ES is an independent, nonpartisan organization and is widely recognized as an influential and pragmatic voice on climate issues. Our mission is to advance strong policy and action to reduce GHG emissions, promote clean energy, and strengthen resilience to climate impacts. We believe a sound climate strategy is essential to ensuring a strong, sustainable economy.

Our goal is to focus on real-world solutions, which we seek to identify and advance through our convening and collaboration with the business community, federal, state and local governments, and other stakeholders. Our efforts include:

- Engaging with negotiators from around the world to help them fulfill the Paris Agreement;
- Bringing together Fortune 500 companies through our Business Environmental Leadership Council (BELC), a group of 34 industry leading, mostly Fortune 500 companies;

- Partnering with the U.S. Conference of Mayors to help mayors and business leaders work together to reduce greenhouse gas emissions; and
- Co-convening the Carbon Capture Coalition to build support for development and deployment of clean energy technologies.

Since early 2018, C2ES has worked with companies to frame a comprehensive U.S. response to climate change through our Climate Innovation 2050 initiative. We brought together businesses from a variety of sectors to develop a long-range, economy-wide decarbonization strategy. As part of that effort, we identified a set of near-term federal actions to address climate change. That plan, released in February, includes fulfilling the goals of the legislation we consider here today: providing more funding and action-oriented program direction for the Department of Energy's research and development of clean energy and GHG-reducing technologies.

Carbon Capture's Role in a Decarbonized Economy

We believe that the capture, utilization and storage of carbon oxides—referred to collectively as "carbon capture"—is an essential component of a comprehensive response to climate change. Nearly 40 million tons of carbon dioxide are annually captured and stored around the world, demonstrating that carbon capture is both proven and has untapped potential as a climate tool.

Moreover, we believe that the Department of Energy's Fossil Energy (DOE FE) R&D program can and should be a key driver in accelerating the deployment of carbon capture technologies. While our focus at C2ES is on climate, we strongly believe that carbon capture can be a win-win for the economy. The United States is the recognized global leader in research and deployment of carbon capture, and Congress has the opportunity to enhance that leadership as it considers legislation like the bills before the Committee today.

In 2011, C2ES and the Great Plains Institute together helped to create a coalition of businesses, labor unions, nonprofits (NGOs), and technology and project developers in support of reforming and extending the 45Q tax credit for carbon storage.

Our collective efforts were successful: In February of last year, Congress enacted a new tax credit aimed at encouraging geologic storage of carbon dioxide, both in saline formations and through enhanced oil recovery, along with utilization of carbon oxides and direct air capture of carbon dioxide. Meanwhile, besides passage of the new tax credit, much has changed since 2011:

- Stakeholder support for carbon capture has grown stronger, as evidenced by the diversity of the more than 60 organizations that now participate in the Carbon Capture Coalition;
- That stakeholder support is well-reflected in Congress, where members of both parties from varying regions of the country have expressed their support for policy action to reap the potential of carbon capture's environmental and economic benefits;
- Carbon capture's potential has grown steadily, as technology has improved and the climate imperative has increased;
- The consensus has grown that carbon capture represents an essential component in the world's collective response to climate change; but

- So, too, has the concern that we are "behind the curve" in deploying carbon capture, if it is to provide the needed portion of GHG reduction.

From a climate standpoint, the International Energy Agency's modeling of climate responses repeatedly has found that, if the 2050 two-degree warming scenario is to be met, approximately 12–15 percent of GHG reductions must come from carbon capture. IEA additionally found that removing carbon capture from the emission reduction toolbox would *more than double* the cost of keeping warming below two degrees. In other words, carbon capture has a significant role in cost-effectively reducing GHG emissions and preventing the worst impacts of climate change.

The reasons for this are intuitive. The recent growth in renewable energy is desirable and serves as proof that supportive government policies can succeed in taking energy technologies from work bench to the commercial scale. However, we believe the most effective and economical path to decarbonization would include a variety of other technologies in addition to renewables. In the power sector, when the penetration of renewables reaches 50-60 percent, the intermittency of the sources becomes increasingly more expensive to manage. Therefore, some level of dispatchable, *emissions-abated* fossil-powered generation likely will remain necessary for decades to come (along with other non-emitting baseload power sources like hydropower, geothermal, existing nuclear, and new small and advanced modular nuclear power plants).

Second, the manufacture of products such as steel, cement, and methanol emit greenhouse gases as part of their manufacturing processes. These emissions represent approximately 22 percent of U.S. GHG emissions, and the most effective (and in some cases, the only) option for abating them is carbon capture.

While the 45Q tax credit will provide a boost for project financing (once the Internal Revenue Service issues its long-awaited guidance), a suite of supportive policies is needed if the pace of carbon capture deployment is to accelerate, especially to address two critical aspects: the continued improvement in available technologies, and the reduction in the associated costs. That brings us to the legislation before the Committee today.

Fossil Energy Research and Development Act

While the post-combustion capture of carbon dioxide has been theoretically possible for generations, the constant improvements in efficiency and cost made possible through the DOE Fossil Energy R&D program have improved carbon capture's viability as an emissions tool. The FE R&D program has been responsible for many of those improvements in carbon capture technology through work led by DOE's National Energy Technology Laboratory (NETL) headquartered outside Pittsburgh.

NETL's Carbon Capture Program research is aimed at providing step-change reductions in both cost and energy penalty compared to currently available technologies. The program supports research projects that develop and test a variety of carbon dioxide control technologies, including advanced solvents, sorbents, and membranes.

The scale of NETL's research ranges from lab/bench-scale testing, through small pilot-scale testing, up to large pilot-scale demonstration scale testing. Many NETL-sponsored carbon capture technologies have progressed through numerous cooperative agreements from successful bench-scale testing, and some technologies have moved beyond NETL sponsorship and are being used commercially.

As cost is a major factor in eventual deployment, reducing it is an intrinsic part of this work. From an estimated average cost of capture that, in 2012, sat in the neighborhood of $80-100 per metric ton of carbon dioxide, DOE hopes to achieve a capture cost of $45 per ton by next year and $30 per ton by 2030. Reducing the cost factor to that level will improve carbon capture's viability and acceptance to private sector efforts to decarbonize.

Despite these achievements, the program still operates under its 2005 authorization, thus many of its current research objectives weren't even envisioned by Congress at that time. For instance, the concept of carbon utilization—the beneficial use of captured carbon oxides in commercial products such as building materials, fuels, and chemicals—was barely imagined when the FE R&D program was last authorized. Now it offers an important economic pathway to decarbonization in hard-to-decarbonize products and geographic areas (*i.e.,* where geologic storage options may be limited).

The *Fossil Energy Research and Development Act* brings the program's statutory direction into the modern era. It would provide updated program guidance while allowing for flexibility as priorities and technologies change. Building off the concept of the National Carbon Capture Center, it would establish regional centers to address region-specific capture, storage, and utilization needs. And it would provide higher funding authorization levels. On this last point, we suggest you will find widespread agreement among a wide variety of stakeholders, including the private sector and NGOs, that the higher authorization levels that this authorization lays out would support more rapid deployment of technologies.

In particular, the FE R&D program has been responsible for important advances in the development of technologies for carbon utilization, also known as carbon recycling. C2ES believes carbon utilization holds great promise as a pathway for decarbonization and will soon publish a new report on the subject. Its conclusions are relevant to both bills before the Committee today.

Carbon utilization (beyond that involving enhanced oil recovery) can be especially effective in addressing harder-to-decarbonize industrial sectors. For instance, aviation fuel emissions cannot be "captured" in real time by traditional means, but their lifecycle emissions may be reduced pre-combustion by converting low-carbon ethanol produced from captured waste emissions into jet fuel.

The draft Fossil Energy R&D Act would strengthen DOE's mission to develop these technologies, while the industrial decarbonization bill could lead to a stronger government-wide action plan on how carbon utilization can be applied to address emissions at particular industrial locations. Our research shows that both the market and GHG reduction potential of carbon utilization is great. However, if carbon utilization technology and markets have not developed within the next decade to the point where commercial forces are driving continued growth, the contribution of utilization to decarbonization may never catch up. We believe legislation like that before the Committee today could quickly accelerate carbon utilization's development and deployment.

Industrial Decarbonization Technology Development Act

As mentioned previously, much of the government's focus on decarbonization has gone to the power sector, which, according to the U.S. EPA, accounted for 28 percent of GHG emissions in 2017 versus decarbonization of industrial processes responsible for 22 percent of GHG emissions in the same period.

Emissions from industry subsectors such as steel, concrete, aluminum, and chemicals are challenging because they are energy-intensive and process-related, intrinsic to the product with no readily available alternative. For example, cement is commonly made by melting limestone and thereby releasing carbon dioxide (although research on lower-emitting cement-making processes is among innovative carbon utilization technologies being considered by the Carbon XPRIZE competition).

C2ES suggests that a successful approach to addressing industrial GHG emissions would be multi-faceted, both in terms of addressing the emissions themselves and in setting other complementary market-driving decarbonization policies. It would double down on both capture and utilization technology R&D specifically applicable to industrial processes. It would facilitate transportation of carbon dioxide emissions (*e.g.*, through pipelines) from the industrial sources to either geologic storage formations, or to where the carbon dioxide could be utilized in enhanced oil recovery or the making of products. And it would provide at least a level playing field for financing and taxation of these operations in comparison with natural resource development and renewables.

Lastly, C2ES strongly believes that enacting some form of a carbon pricing system would provide a positive market-oriented force that would help to "pull" these other elements along as industries incorporate GHG emissions abatement into how they do business, as they previously have done with reducing other types of emissions. While this is outside the Committee's jurisdiction, we urge every Member of Congress to consider how such a system would help foster a lower-carbon economy.

The development and deployment of lower- and non-emitting industrial processes is an important goal, but technology development is only one aspect of industrial decarbonization. In addition, other relevant solutions may include incorporating carbon capture into those processes (linking it to carbon utilization applications) and adoption of carbon capture for on-site power generation.

Carbon capture is currently in use at-scale (i.e., capturing at least one million tons of carbon dioxide per year) at two industrial plants in the United States, including Air Products' hydrogen production facility in Texas and Archer Daniels Midland's ethanol production facility in Illinois. However, significantly more and different types of industrial decarbonization projects will be needed in the coming decades.

The draft *Industrial Decarbonization Technology Development Act* (IDTD) would elevate the issue of industrial GHG emissions within the government and provide better cross-agency coordination of policy. It would establish a Transformative Industrial Technology Program led by DOE to leverage existing resources among relevant agencies, and enable grants, contracts, cooperative agreements, and public-private partnerships to carry out the program. The bill would also seek better intergovernmental cooperation on industrial emissions and would require development of a national roadmap for decarbonization of difficult-to-decarbonize industries.

C2ES believes these are good first steps. In particular, the IDTD acknowledges that, as state and local governments increasingly adopt their own environmental and energy plans, the alignment of policies between federal, state, and local policies is critical. Industrial challenges for steelmaking in Pennsylvania are different from those for chemical processing in Texas, and the federal government must encourage their local and state

counterparts to formulate and implement their own industrial emissions plans specific to their own economies.

We understand that a companion bill to the IDTD is being developed concurrently in the Senate, and we commend the Committee for seeking to address the issue. As your legislative draft advances, we stand ready to offer our ability to convene stakeholders for the purpose of continuing the process of developing an effective action plan. We suggest that addressing the issue of industrial decarbonization should be on the short list of priorities as Congress considers how to craft national climate policy.

Setting a Successful GHG Reduction Policy

On the subject of process, allow me to comment on how this Committee has gone about developing these bills. While the industrial decarbonization bill is relatively new, the drafting of the Fossil Energy R&D legislation should be considered a model for stakeholder engagement and bipartisan legislative drafting. Committee members and staff on both sides of the aisle are to be commended for conducting an open and thorough process.

I first heard of the effort to reform the FE R&D program more than two years ago when the then-minority staff reached out to me and other stakeholder groups asking that we offer our views on the subject. Through countless meetings and many iterations, the objective remained steady: How can we authorize the most effective program? No bill can please everyone, but a process that takes many views into account is more likely to succeed.

Allow me to close with a thought about the general notion of "innovation" and how it relates to the broader policy scheme that will be needed if Congress hopes to accelerate carbon capture deployment. Innovation is not an end in itself, but rather a critical means to deploying more effective and economical technologies that will lead to the greatest possible GHG reduction. The seeds planted by federally supported innovation will not bear fruit without other policies mentioned earlier, without commensurate action at the local and state levels, and certainly not without strong commitment by the private sector to shoulder some of the risk.

To be sure, innovation benefits from strong, strategic federal funding. We believe this is an area where every additional dollar has the potential for accelerating our transition to a lower-carbon economy and for maintaining U.S. global leadership in that quest.

Lastly, innovation succeeds only with follow-through. The single metric of success in this case should be the number of new projects in the ground and the corresponding GHG reductions they represent. On the other hand, if projects are instead falling into the financial "valley of death" before they reach commercial scale, something is wrong. An innovative project that never happens is a far poorer public investment than one that needs one last federal boost to reach scale.

We believe Congress's response to climate must be both urgent and comprehensive. No proposed single policy reform offers a "silver bullet;" rather, a portfolio of policies is needed to address technology development, financing, and market preferences. Moreover, federal action alone is not sufficient. States and local governments can best tailor policies that will reap the maximum environmental and economic benefits of developing carbon capture.

And we are behind. As I said at the beginning, that nearly 40 million metric tons of carbon dioxide are currently stored or utilized annually around the world proves that carbon capture can play a major role in GHG reduction. However, according to the International Energy Agency, the amount of carbon dioxide captured needs to grow by *a factor of 100 by 2040* if carbon capture's necessary contribution to GHG reduction is to keep pace.

We commend the Committee for proactively proposing thoughtful climate policies within its jurisdiction and we look forward to working with you going forward. Thank you for your attention.

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C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

Jeffrey Bobeck
Director, Energy Policy Engagement
Center for Climate and Energy Solutions (C2ES)

Jeffrey Bobeck brings three decades of policy experience to C2ES, where he serves as Director of Energy Policy Engagement.

Jeff leads the work of C2ES in co-convening the national Carbon Capture Coalition. In that role, he directs stakeholder work groups on carbon utilization and natural gas/carbon capture.

Jeff's government experience includes serving on the staffs of two senior Members of the U.S. House of Representatives, where he contributed to major tax and international trade legislation, and was designated as an official observer to the negotiations to end the war in El Salvador. In 2006, President George W. Bush appointed him Director of Communications and External Affairs for the U.S. Department of Energy.

In the private sector, Jeff served as Director of External Liaison with the American Automobile Manufacturers, where he focused on international harmonization of automotive environmental and safety regulations. He testified annually before Congress on the implementation of the North American Free Trade Agreement (NAFTA) and later helped to manage the auto industry's North American environmental sustainability coalition which was authorized by NAFTA's environmental side agreement. He later served as the Washington-based North America policy lead for the Global CCS Institute.

Jeff has contributed numerous op-eds to publications such as the *Washington Post* and *New York Times*, appeared on national news outlets including CNN and NPR, and is a frequent speaker at energy and environmental policy conferences.

He is a graduate of Ohio University in Athens, Ohio, and has done graduate work in environmental and security policy at George Washington University in Washington, DC

Chairman LAMB. Thank you. Ms. Burns.

TESTIMONY OF ERIN BURNS,
DIRECTOR OF POLICY, CARBON180

Ms. BURNS. Thank you for the opportunity to testify today. I'm the Director of Policy at Carbon180, which is an NGO focused on carbon capture, removal, and use with the goal of building an economy that sequesters more carbon dioxide than it emits. We choose to work on these issues for one reason: Climate. We have a responsibility to take immediate and ambitious steps to avoid the worst impacts of climate change, and carbon removal, alongside renewables, energy efficiency, and other emissions reduction efforts, can play an integral role in eliminating global emissions.

At the same time, we also have an opportunity to turn these carbon emissions into an asset, spurring American innovation and growth. We are supportive of the *Fossil Energy Research and Development Act*, as well as the *Industrial Decarbonization Technology Development Act*. My testimony will focus primarily on the first bill, which we support for three major reasons.

First, this bill establishes the first-ever dedicated carbon removal program at the Department of Energy. That term carbon removal refers to a broad set of technologies and practices that remove carbon dioxide from the ambient air all around us and includes a technology called direct air capture. While direct air capture is a relatively new technology, there are nearly a dozen small-scale plants deployed today with plans recently announced to build a plant that would build remove half a million tons of carbon dioxide a year.

To bring this technology to scale in time to meet climate goals and to maintain American leadership on innovation it's time for the Federal Government to significantly increase support for carbon removal. Luckily, we know how best to do that. Toward the end of last year, the National Academies of Sciences (NAS) released a report that detailed how the Federal Government can effectively move carbon removal forward. One of their most important recommendations was to implement an ambitious Federal Research, Development, Demonstration, and Deployment program for direct air capture and other carbon removal approaches.

To date, the Department of Energy has spent around $11 million ever on direct air capture, far below the tens and hundreds of millions of dollars of annual funding recommended in this NAS report. This legislation would scale up those efforts and get us far closer to the levels recommended. The Office of Fossil Energy has a long history of work on carbon capture technologies, and that expertise is well-suited to tackling the challenges around other technologies like direct air capture.

The second reason we support this bill is because it expands the carbon capture program to include natural gas and industrial applications. With the rapid growth of natural gas in the U.S., it is essential that the Office of Fossil Energy expand its historical focus beyond carbon capture applications for coal power plants to also include work on natural gas plants.

Carbon capture is also essential to reducing emissions in the industrial sector, which represent about around one-fifth of total U.S. emissions. We need to begin decarbonizing the production of steel,

cement, and other industrial processes today. Efficiency, certain renewables, applications, and advanced nuclear can all play a role. However, carbon capture will continue to be an important part of decarbonizing this sector. The provisions in this bill to incorporate work on carbon capture for natural gas and industrial plants reflect the reality of our changing electricity generation mix and are key to helping us meet climate goals.

We are also very supportive of the *Industrial Decarbonization Technology Development Act*. It is essential that the U.S. work on a broad set of technologies, including but not limited to carbon capture, to rapidly reduce and eliminate industrial emissions. This bill is an enormously important step toward that goal.

The third and final reason we support the *Fossil Energy Research and Development Act* is because it builds on the Office of Fossil Energy's great work on carbon utilization. Taking carbon dioxide from smokestacks or the ambient air and turning it into commercial products such as plastics, fuels, or building materials is what we call carbon tech, and it offers a promising near-term opportunity to begin commercializing the technologies needed for an economy where we remove more carbon than we emit. There are dozens of these carbon tech companies and startups in the United States today, and the U.S. is home to more of these projects than any other country in the world.

We have an opportunity to build a significant domestic carbon tech industry. In fact, according to our analysis, there's a $1 trillion total available market for these products in the U.S. alone and a nearly $6 trillion total available market globally.

To date, the Office of Fossil Energy has spent only about $10-$12 million annually on carbon tech research and demonstration funding. They've done some really great work, but they can do more and better work. This bill would nearly triple our current annual investment in these technologies and put the U.S. in a much stronger position to fully take advantage of this enormous economic opportunity.

Carbon capture and removal are key to addressing climate change and can help drive economic growth, and Federal policy action today can help unlock both opportunities. As Congress considers climate policies like this bill, we recommend looking to examples like the Carbon Capture Coalition and similar efforts where a broad set of participants, including environmental organizations, labor unions, startups, large companies, and others have helped drive policy development and advocacy. Engagement with labor unions in particular, who have been foundational for carbon capture work historically, is key to unlocking the full economic potential of carbon capture, removal, and use.

Thank you again for the opportunity to be here today. Carbon180 strongly supports the *Fossil Energy Research and Development Act* and the *Industrial Decarbonization Technology Development Act*, and we are grateful for the hard work of the Committee, staff, and others who have put these bills together. And I look forward to your questions. Thank you.

[The prepared statement of Ms. Burns follows:]

Testimony of Erin Burns, Director of Policy, Carbon180
U.S House of Representatives Committee on Science, Space, and Technology
June 19, 2019
Hearing on Fossil Energy Research: Enabling our Clean Energy Future

Introduction

Thank you for the opportunity to testify about the Fossil Energy Research and Development Act today. I'm Erin Burns and I'm the Director of Policy at Carbon180, which is an NGO focused on carbon capture, removal, and use with the goal of building an economy that sequesters more carbon dioxide than it emits.

We choose to work on these issues for one primary reason: climate. We have a responsibility to take immediate and ambitious steps to avoid the worst impacts of climate change, and carbon removal — alongside renewables, energy efficiency, and other emissions reduction efforts — can play an integral role in eliminating global emissions. At the same time, we also have an opportunity to turn those carbon emissions into an asset, spurring American innovation and economic growth.

We are supportive of the Fossil Energy Research and Development Act, as well as the Industrial Decarbonization Technology Development Act. My testimony will focus primarily on the first bill, which we support for three major reasons.

Carbon Removal

First, this bill establishes the first-ever dedicated Carbon Removal Program at the Department of Energy.

The term 'carbon removal' refers to a broad set of technologies and practices that remove carbon dioxide from the ambient air all around us, and includes a technology called direct air capture. While direct air capture is a relatively new technology, there are nearly a dozen small-scale plants deployed today with plans recently announced to build a plant that would remove half a million tons of carbon dioxide a year. To bring this technology to scale in time to meet climate goals and to maintain American leadership on innovation, it's time for the federal government to significantly increase support for carbon removal. Luckily, we know how best to do that.

Towards the end of last year, the National Academies of Sciences released a report that detailed how the federal government can effectively move carbon removal forward. One of their most important recommendations was to implement an ambitious federal research, development, demonstration, and deployment program for direct air capture and other carbon removal

approaches. To date, the Department of Energy has spent around $11 million ever on direct air capture, far below the $10s and $100s of millions of dollars of annual funding recommended in the report.

This legislation would scale up those efforts and get us far closer to the levels the National Academies recommends. The Office of Fossil Energy has a long history of work on carbon capture technologies and that expertise is well-suited to tackling the challenges around technologies like direct air capture.

Natural Gas and Industrial Sources

The second reason we support the Fossil Energy Research and Development Act is because it expands the Carbon Capture Program to include natural gas and industrial applications.

With the rapid growth of natural gas in the U.S., it is essential that the Office of Fossil Energy expand its historical focus beyond carbon capture applications for coal power plants to include work on natural gas plants.

Carbon capture is also essential to reducing emissions in the industrial sector, which represent around ⅛ of total U.S. emissions. We need to begin decarbonizing the production of steel, cement, and other industrial processes today. Efficiency, certain renewables applications, and advanced nuclear can all play a role. However, carbon capture will continue to be an important part of decarbonizing this sector.

The provisions in this bill to incorporate work on carbon capture for natural gas and industrial plants reflect the reality of our changing electricity generation mix and are key to helping us meet climate goals.

We are also very supportive of the Industrial Decarbonization Technology Development Act. It is essential that the U.S. work on a broad set of technologies, including but not limited to carbon capture, to rapidly reduce and eliminate industrial emissions. The robust funding in this bill is an enormously important step towards that goal.

Carbontech

The third reason we support the Fossil Energy Research and Development Act Act is because it builds on the Office of Fossil Energy's great work on carbon utilization. Taking carbon dioxide from smokestacks or the ambient air and turning it into commercial products, such as plastics, fuels or building materials, is what we call carbontech, and it offers a promising near-term opportunity to begin commercializing the technologies needed for an economy where we remove more carbon than we emit.

There are dozens of these carbontech companies and start-ups in the U.S. today and the U.S. is home to more of these projects than any other country in the world. We have an opportunity to build a significant domestic carbontech industry. In fact, according to our analysis, there is a $1 trillion total available market for these products in the U.S. alone and a nearly $6 trillion total available market globally.

To date, the Office of Fossil Energy has spent only about $10 to $12 million annually on carbontech research and demonstration funding. They've done some great work. But they can do more and better work. This bill would nearly triple our current annual investment in these technologies and put the U.S. in a much stronger position to fully take advantage of this enormous economic opportunity.

Conclusion

Carbon capture and removal are key to addressing climate change and can help drive economic growth, and federal policy action today can help unlock both opportunities. As Congress considers climate policies, like this bill, we recommend looking to examples like the Carbon Capture Coalition and similar efforts where a broad set of participants, including environmental organizations, labor unions, start-ups, large companies, and others have helped drive policy development and advocacy. Engagement with labor unions, in particular, who have been foundational for carbon capture work historically, is key to unlocking the full economic potential of carbon capture, removal, and use.

Thank you again for the opportunity to be here today. Carbon180 strongly supports the Fossil Energy Research and Development Act and the Industrial Decarbonization Technology Development Act, and we are very grateful for the hard work of the Committee staff and others who have put these bills together, and I look forward to your questions. Thank you.

Additional Comments

Direct Air Capture

Towards the end of last year, the United Nations Intergovernmental Panel on Climate Changed released their "Special Report: Global Warming of 1.5 °C." In this report, scientists found that carbon removal will almost certainly be required in all pathways that keep us within 1.5 °C of warming.[1]

[1] https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

Around the same time, the National Academies of Sciences released a report titled, "Negative Emissions Technologies and Reliable Sequestration: A Research Agenda," which detailed how the federal government can move carbon removal forward. One of the most important recommendations in their report was to implement an ambitious research, development, demonstration, and deployment (RDD&D) program for direct air capture (DAC) and other carbon removal approaches. The recommended program for DAC ranges between $60 and $240 million annually.[2] (We've compiled a list of the key takeaways from the report here.) To date, the Department of Energy (DOE) has cumulatively spent around $11 million ever on direct air capture. Getting to the level of funding in the NAS report will require a serious ramp up; however this increase in funding will need to be done on a timeline that allows the DOE to establish and scale up their first-ever dedicated Carbon Removal Program.[3] We believe the Fossil Energy Research and Development Act strikes this balance with funding in the roughly $60 to $70 million a year range.

We also appreciate and agree with the bill's recognition of the Office of Energy Efficiency and Renewable Energy's Bioenergy Technologies Office's (BETO) role in supporting the RDD&D of DAC. BETO has historically been involved in the DOE's work on DAC and some of the issues related to DAC deployment, including integration with renewable power, necessitate cross-program coordination.

Right now is an especially important time for the DOE to expand its work on DAC. After the passage of the updates to the 45Q tax credit in February 2018 to include DAC for the first time, we have seen increasing interest from the investment community in supporting these technologies.[4] In particular, Carbon Engineering, a leading DAC company, has had two major announcements in the past several months. The first was a $68 million investment from Occidental Petroleum and Chevron earlier this year.[5] The second was the recent announcement that Carbon Engineering is beginning engineering work on what will be the world's largest DAC plant at half a million tons.[6]

DOE has experience supporting first-of-a-kind projects and this support has been key in scaling up other climate and clean energy technologies. In fact, the NAS specifically states, "The U.S. Department of Energy's Office of Fossil Energy and National Energy Technology Laboratory (NETL) has the appropriate infrastructure to manage direct air capture, research, development, and demonstration projects through a typical grant process that distributes funds to projects at

[2] https://www.nap.edu/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda
[3] https://bipartisanpolicy.org/wp-content/uploads/2019/03/Carbon-Removal-Comparing-Historical-Investments-with-the-National-Academies-Recommendations.pdf
[4] https://medium.com/@carbon180/the-case-for-investing-in-direct-air-capture-just-got-clearer-e08be7f35a83
[5] https://carbonengineering.com/carbon-engineering-concludes-usd68-million-private-investment-round/
[6] https://carbonengineering.com/worlds-largest-direct-air-capture-and-sequestration-plant/

universities, nonprofit research organizations, start-up companies, and large companies."[7] DOE has significant experience with these types of efforts. The Petra Nova plant in Texas, the only commercial carbon capture power plant in the United States and one of only two globally, benefitted from a DOE grant.[8] Similarly, the Illinois Industrial Carbon Capture and Storage project has received both DOE and private sector funding and is the only large-scale bioenergy with carbon capture plant in the world.[9] This project is also notable because it incorporates geologic storage, which will be vital to the long-term success of carbon capture and removal. DOE is also well-positioned to continue work on BECCS given the success of the Biomass Research and Development Initiative[10] and ARPA-E's TERRA,[11] both of which aim to develop highly efficient and sustainable bioenergy feedstocks.

The NAS report goes on to suggest that "For development and demonstration testing of direct air capture components and systems, a centralized facility/national testbed akin to the NETL's National Carbon Capture Center...is recommended." We believe the bill's inclusion of a dedicated Direct Air Capture Test Center implements this particular recommendation and builds on the DOE's existing expertise.

Finally, continued policy support, including federal RDD&D, can help drive down technology and deployment costs of DAC. A recent report from the Rhodium Group, "Capturing Leadership: Policies for the U.S. to Advance Direct Air Capture," argued that with current DAC technology and no additional innovation, costs could end up at less than $50 per ton.[12] Innovation from public-private partnerships could further drive down these costs.

With federal policies like 45Q, increased interest from the investment community, and the NAS roadmap, now is the time for DOE to scale up their work on DAC. We believe the approach in the Fossil Energy Research and Development Act — establishing a dedicated and well-funded Carbon Removal Program — is the best path forward.

Other Carbon Removal Pathways

The term 'carbon removal' encompasses a broad set of engineered, biological, and hybrid pathways for removing carbon dioxide from ambient air. Below is a figure from the New Carbon

[7] https://www.nap.edu/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda, page 243

[8] https://www.nrg.com/case-studies/petra-nova.html

[9] https://www.energy.gov/fe/articles/doe-announces-major-milestone-reached-illinois-industrial-ccs-project

[10] https://nifa.usda.gov/funding-opportunity/biomass-research-and-development-initiative-brdi

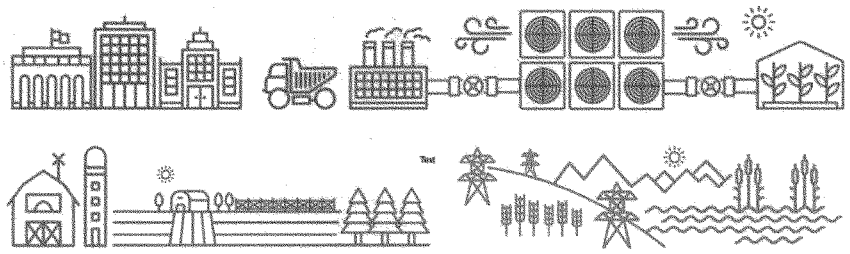
[11] https://arpa-e.energy.gov/?q=arpa-e-programs/terra

[12] https://rhg.com/wp-content/uploads/2019/05/Rhodium_CapturingLeadership_May2019-1.pdf

Economy Consortium's report, "Building a New Carbon Economy: An Innovation Plan," which provides additional details on these pathways.[13]

FIGURE 1. ***Solutions in a New Carbon Economy***

The knowledge foundation of the new carbon economy spans many disciplines and economic sectors.



ENGINEERED SOLUTIONS, which include technologies and systems that capture, convert, and store CO_2 from the air and oceans, such as direct capture of CO_2 from air and point sources, converting CO_2 into valuable products (e.g., concrete or fuels), and the accelerated mineralization of CO_2 for sequestration.

BIOLOGICAL SOLUTIONS, which include the use of working forests and farmland to store carbon, increase yields, and improve ecosystem functions. Biological solutions include ecosystem restoration, improved forestry practices, changes in agricultural practices, developing soil amendments that improve soil health, and cultivating and converting algae into valuable products such as fertilizer and animal feed.

HYBRID SOLUTIONS, in which biological and engineered pathways come together to create energy and/or products. Hybrid energy solutions can include bioenergy with carbon capture, biochar production, waste-to-energy systems, and carbon-cultivating aquaculture.

The Carbon Removal Program authorized in this bill extends beyond technological removal — DAC, bioenergy with carbon capture and storage (BECCS), and carbon mineralization — to include removal on natural and working lands. Recent research has demonstrated that the United States' natural and working lands can capture and store a significant portion of our emissions, while also increase the productivity of the agricultural and forestry sectors.[14] The inclusion of both natural and technological CDR is important as leading analysis has indicated both will be necessary to avoid catastrophic climate change impacts.[15] Additionally, natural carbon removal

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13 https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/5b98383aaa4a998909c4b606/1536702527136/ccr02.innovationplan.FNL.pdf

14 https://advances.sciencemag.org/content/4/11/eaat1869?utm_source=TrendMD&utm_medium=cpc&utm_campaign=TrendMD_1

15 https://iopscience.iop.org/article/10.1088/1748-9326/aabf9f/meta

solutions are comparatively more affordable, offer a suite of environmental co-benefits, and provide a valuable rural development opportunity.[16] We believe the bill appropriately prioritizes technological removal, as it fits well within the DOE's expertise and experience supporting the commercialization of carbon capture.

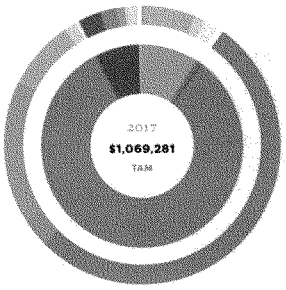
Carbontech

We use the term 'carbontech' to refer to an emerging sector where value is created from the conversion of industrial and atmospheric carbon to fuels, fertilizers, chemicals, plastics, materials, and other commercial products. Carbontech represents a $1 trillion total available market in the U.S. alone and a nearly $6 trillion market globally.[17] Below is a table that breaks out this market by sector.

[16] https://www.wri.org/publication/land-carbon-removal-usa
[17] https://carbon180.org/carbontech-labs-reports

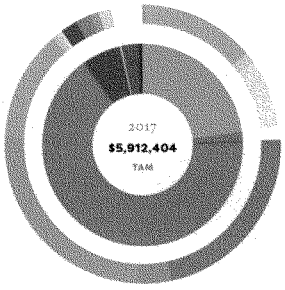
KEY CARBONTECH MARKET SEGMENTS AND FINDINGS

US



PRODUCT	$ IN MILLIONS
BUILDING MATERIALS	$101,130
Cements	$1,240
Concretes	$65,000
Asphalts	$12,190
Aggregates	$22,700
WOOD-BASED PANELS	$12,508
FUELS	$882,149
Gasoline	$543,400
Jet Fuel	$38,760
Diesel	$186,660
Natural Gas	$83,705
Ethanol	$25,550
Biodiesel	$6,074
PLASTICS	$71,694
High density polyethylene	$25,393
Linear low density polyethylene	$20,502
Low density polyethylene	$13,522
Polypropylene	$14,276
CHEMICALS	$1,800
AGRICULTURE AND AQUACULTURE	N/A
CONSUMER GOODS	N/A
TOTAL	$1,069,281

GLOBAL



PRODUCT	$ IN MILLIONS
BUILDING MATERIALS	$1,368,100
Cements	$24,900
Concretes	$860,000
Asphalts	$77,200
Aggregates	$466,000
WOOD-BASED PANELS	$96,513
FUELS	$3,821,316
Gasoline	$1,261,000
Jet Fuel	$214,318
Diesel	$1,530,080
Natural Gas	$775,242
Ethanol	$36,720
Biodiesel	$23,956
PLASTICS	$412,448
High density polyethylene	$128,250
Linear low density polyethylene	$103,546
Low density polyethylene	$68,331
Polypropylene	$122,342
CHEMICALS	$20,217
AGRICULTURE AND AQUACULTURE	$169,450
CONSUMER GOODS	$24,360
TOTAL	$5,912,404

Today, the U.S. has an advantage in carbontech, as we have more companies and projects in this field than any other single country.[18] There is also increasing interest from the investment community, ranging from start-up accelerators like Y Combinator and our own Carbontech Labs to larger groups like the Oil and Gas Climate Initiative (OGCI) and Bill Gates's Breakthrough Energy Ventures. Federal policy can catalyze this interest and unlock further investment to fully leverage the economic opportunity of carbontech.

[18] https://www.thirdway.org/graphic/carbon-capture-projects-map

Industrial Carbon Capture

Climate policy often focuses on what is needed to decarbonize the electricity sector. While this is undoubtedly important, particularly as we move to electrify transportation and other sectors, we need to also consider other major sources of emissions.[19] The industrial sector directly accounts for around 1/5 of total U.S. emissions; factoring in emissions from the electricity used by this sector, it accounts for around 29% of total U.S. emissions — making it the single largest emitting sector.[20]

Often, very high temperatures are required for industrial processes and while we need to be researching and developing direct zero-carbon methods to provide those temperatures, right now, that mostly means burning fossil fuels. We should be using carbon capture to prevent those emissions from entering the atmosphere. Even once we are able to replace fossil fuels with other options, there will still likely be a role for carbon capture. Producing cement creates a chemical reaction which results in carbon dioxide — it isn't just the burning of fossil fuels, but the actual production of this material we use every day that creates carbon dioxide. Right now, carbon capture is the only technology we have to keep those emissions from contributing to climate change.

While we expect carbon capture to be essential to decarbonizing industry, there are several other technologies and practices that can play a major role. The Industrial Decarbonization Technology Development Act recognizes this fact and authorizes an appropriately ambitious program to scale these solutions.

[19] https://www.globalccsinstitute.com/resources/publications-reports-research/industrial-ccs/

[20] https://www.thirdway.org/report/industry-matters-smarter-energy-use-is-key-for-us-competitiveness-jobs-and-climate-effort

Erin Burns Biography

Erin Burns is the Director of Policy at Carbon180, a climate NGO focused on carbon removal. There she works with scientists, entrepreneurs, academics, and policymakers to create and inform federal policy on carbon capture, removal, and use. Previously, she worked in the Senate where she handled energy, environment, labor, and agricultural issues, including staffing for the Energy and Natural Resources Committee and the Public Lands Subcommittee. She also worked at Third Way, a DC-based think tank, managing carbon capture and removal, innovation, and other clean energy policy advocacy. A native of southern West Virginia, she has worked on issues related to coal worker and coal community transitions throughout her career. She holds a degree in Cultural Anthropology from Carnegie Mellon University.

Chairman LAMB. Thank you. And, Dr. Webb.

TESTIMONY OF DR. ERIK K. WEBB,
GEOSCIENCE RESEARCH AND APPLICATIONS,
SANDIA NATIONAL LABORATORIES

Dr. WEBB. Chairman Lamb, Ranking Member Weber, and distinguished Members of the Committee, I want to thank you for the opportunity to testify today regarding the importance of fossil energy research.

I'd like to make four points. First, subsurface science is extremely complex and requires a spectrum of research activities that are applied from 10 kilometers below to the surface of the earth and over 12 orders of magnitude in scale. They address the interplay of mechanical, thermal, chemical, biological, and hydrological behavior. Our most challenging program is getting accurate in situ data that represents the heterogeneity in these deep high-temperature and high-pressure environments. Thus, basic materials science and microelectronics research are essential to build new sensing systems to withstand these subsurface conditions.

Sandia is working to integrate this basic science with geomechanical testing, modeling, drilling technology, data tools, and high-performance computing to build a next generation of real-time sensing decision approaches and tools to address this complexity.

Second, subsurface research that is applicable to oil and gas production is equally valuable to enhanced geothermal production, understanding and implementing carbon sequestration, nuclear waste disposal, environmental restoration, basic research in geosciences, water resources management, and multiple national security needs.

Historically, we can see this in the development and application of the polycrystalline diamond compacts that are embedded in drill bits which were successful due to DOE's investment and are now used for the vast majority of oil and gas wells. They are also essential for enhanced geothermal energy production and carbon sequestration, accessing deep crustal basic science research and national security applications.

A more recent example is the EGS Collab project funded by DOE's Geothermal Technologies Office that involves nine national labs and numerous academic and industry partners. This project is studying the interplay of stress, seismicity, and permeability. This understanding is also essential for preventing induced seismicity and accurate global nuclear test detection programs. Additionally, this type of research builds knowledge and tools and human competence to—in preparation for national emergencies such as the Deepwater Horizon, the Aliso Canyon methane leak disaster, and the emerging challenge of wellbore integrity. Utilizing research across these challenges is enhanced when the sponsoring organizations recognize and encourage cross-use of the science space.

Third, the complexity of these earth systems motivates cutting-edge research. The Earth is itself our largest and most complex data set. Efforts such as NASA's Earth-Observing Data and Information System are rapidly digitizing the Earth. However, they estimate the volume of data in this one archive will increase to 247 petabytes by 2025. This is very big data and will truly tax our data

analytic and artificial intelligence tools. One of Sandia's investments in this area is the development of a Real-Time Subsurface Event Assessment and Detection capability we call RESEAD to enable a step change in real-time continuous monitoring, advanced analysis, and decision-based management of the subsurface.

Fourth, the Nation benefits from utilizing the technical capabilities of the whole national laboratory system. The labs do not replace or compete with industry but instead fill a role in early-stage research of high fiscal risk or integrating across multiple disciplines. The National Energy Technology Laboratory is the Department of Energy's lead for fossil energy research. However, investments by other DOE offices builds capability in each of the national laboratories that can benefit fossil energy missions. This works best when the Department of Energy encourages connection across the whole of the national laboratories, academia, and industry. Sandia National Laboratory's experience bears out these four main points.

Thank you for the opportunity to provide testimony on the importance of fossil energy research. I would like to express my gratitude to the team of colleagues at Sandia who helped prepare for this hearing. We are energized by the challenges that face our Nation and are grateful for the attention your Committee pays to them. Thank you for convening this hearing, and I look forward to your questions.

[The prepared statement of Dr. Webb follows:]

Subcommittee on Energy
Committee on Science, Space and Technology
United States House of Representatives
June 19, 2019

Testimony of Dr. Erik K. Webb
Sandia National Laboratories [1]

Chairman Lamb, Ranking Member Weber, and distinguished members of the Committee, I want to thank you for the opportunity to testify today regarding the importance of Fossil Energy Research.

SUMMARY

With this opportunity, I want to make four points:

1. Subsurface Science is extremely complex and requires integration of both basic and applied research
2. Science that helps understand and control the subsurface is applicable across multiple national needs
3. The complexity of Earth systems motivates and facilitates advances in cutting edge research
4. The Nation benefits from utilization of the whole of the national laboratory technical capabilities

MOTIVATION

The research done in fossil energy subsurface and surface infrastructure systems has been essential to our Nation's move toward energy security, sustainability, and stabilizing carbon emissions. The vast majority of the energy currently used by our Nation is derived from the earth's subsurface. In 2017, our domestic oil production was equal to about 90% of our energy consumption.[2] Finding and effectively withdrawing those resources, while mitigating potential adverse effects to the environment can seem, at times, like a daunting challenge; but it is a challenge well suited to Federally Funded Research & Development Centers such as the Department of Energy's National Laboratories. The National Energy Technology Laboratory has a primary role in leading this research, but the complexity and scope of Fossil Energy research challenges require the expertise of not only Sandia, but all national labs in the DOE complex working together to find solutions.

Current research in this area addresses nationally relevant themes including: understanding and expanding the total scale of US recoverable reserves, thus allowing appropriate leasing structures on Federal lands, optimizing US companies and US-based exploration and production in order to reduce the surface footprint of the industry, reducing environmental impacts including surface infrastructure leaks and the threat of well bore integrity failures, induced seismicity, produced water impacts and utilization, and pipeline safety and environmental management.

For the purposes of today I will primarily focus on subsurface research but would be pleased to provide information on surface and engineering research at the Committee's discretion.

SANDIA NATIONAL LABORATORIES ROLE

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[1] Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND2019-6788

[2] https://www.eia.gov/energyexplained/?page=us_energy_home

While Sandia is not the lead Department of Energy Laboratory for Fossil Energy, we fill an important role with unique capabilities and projects that include serving as lead for the subsurface science and sustainment of the Strategic Petroleum Reserve and understanding the fire safety of crude oil transportation by rail.

Additionally, we utilize the extensive investment in engineering science funded by the National Nuclear Security Administration to expand the Nation's energy security to augment the capabilities and leadership of the National Energy Technology Laboratory (NETL) and other DOE Laboratories.

Sandia has developed seven cross-laboratory technical capabilities, known as research foundations, which are of particular importance in maintaining cutting edge research on Earth Science, Bioscience, Computing and Information Science, Engineering Science, Materials Science, Nanodevices and Microsystems and Radiation Effects and High Energy Density Science.

Our use of these foundational technical capabilities have been applied for fossil energy applications in several ways. For example:

Carbon Capture Technologies:

Sandia partnered with the University of New Mexico to develop an ultra-thin enzymatic bubble-like membrane that can efficiently separate and capture CO_2 from coal-fired and gas-fired power plants. The patented technology, referred to as Memzyme, has been tested at the lab scale and is both 100 times faster in passing flue gas than other membranes on the market, and 10-100 times more selective for CO_2 over nitrogen, the main component of flue gas. This work was sponsored internally by Sandia's Laboratory Directed Research and Development (LDRD) program.

Carbon Storage Validation and Testing:

Geological carbon storage (GCS) technology requires the injection of large volumes of CO_2 into subsurface storage reservoirs. Current challenges include: (i) sustaining large storage rates; (ii) using pore space with unprecedented efficiency, and (iii) controlling undesired or unexpected behavior. Sandia has been involved in addressing these challenges through its work within the Center for Frontiers in Subsurface Energy Security (CFSES) in partnership with the University Texas under funding by the Department of Energy's Office of Science Energy Frontier Research Centers (EFRC) Program.

Sandia is part of a long-standing Southwest Partnership led by the University of Utah and the New Mexico Institute of Mining and Technology funded by the DOE Office of Fossil Energy Carbon Storage program. This team-based project has completed an initial study exploring the potential to store CO_2 in geologic conditions. Current work is underway at the Farnsworth Unit in Texas as part of an enhanced oil recovery site using CO_2 captured from ethanol and fertilizer plants that is injected into the underground oil reservoir. Sandia has also conducted investigations relevant to the geomechanics of CO_2 Reservoir Seals. An in-situ fracture tester was developed to examine the effects of CO_2 injection on caprock integrity by measuring the effects of different solutions and their concentrations on fracture velocities.

Sandia developed techniques to ensure CO_2 remains in place once injected under a project titled Nanoparticle Injection Technology for Remediating Leaks of CO_2 Storage Formation. This project, which involved a partnership with the University of Colorado – Boulder, focused on the development of advanced materials and methods that can prevent/remediate leaks in complicated environments under a variety of pressure, temperature, and chemical conditions to

ensure CO_2 permanence within the storage formation. The DOE Office of Fossil Energy funded this work.

Advanced Energy Systems

Sandia is currently developing a scaled demonstration version of the Supercritical Carbon Dioxide Closed Brayton Cycle. Brayton Cycles have the potential to achieve higher energy conversion efficiencies at 1/10th the cost of comparable steam Rankine cycles. The technology is demonstrated in Sandia's Nuclear Energy Systems laboratory/Brayton lab under joint funding from the DOE's Office of Nuclear Energy and the Office of Fossil Energy.

The Institute for the Design of Advanced Energy Systems (IDAES) project specializes in the identification, synthesis, optimization, and analysis of innovative advanced energy systems at scales ranging from process to system to market. Sandia provides the optimization algorithms that help balance design options. Our work is made possible through previous investments made by both the National Nuclear Security Administration (NNSA) and Laboratory Directed Research and Development (LDRD) funding. IDAES is led by the National Energy Technology Laboratory (NETL), in partnership with Sandia, Lawrence Berkeley National Laboratory (LBNL), Carnegie Mellon University, and West Virginia University.

Rare Earth Element Extraction

Rare earth elements are critical for energy and national security, and the development of novel separation approaches impacts both. Sandia is in the process of patenting a novel separation technique for individual Rare Earth Elements developed at the lab-scale under LDRD- based funding and anticipate the use of this technology in future DOE and Industry applications testing.

Carbon Removal from the air

In partnership with Lawrence Livermore National Laboratory, Sandia now utilizes an "algal racetrack," at our site in Livermore, California to study the biological and environmental conditions and resilience of algal communities for CO_2 extraction from the atmosphere. This project has the potential to remove toxic metals such as selenium from water, and to develop feedstocks for other industrial processes. The Department of Energy's Office of Fossil Energy sponsored this work.

Monitoring and Accounting for Carbon Management and Removal

The largest source of methane (natural gas) emissions, as seen at the Aliso Canyon natural gas leak, are the result of emissions from the natural gas transmission system during petroleum and natural gas production. The detection, mitigation, and response to methane leaks requires an understanding of the sensors, systems, wellbore integrity, concrete, and the ability to provide emergency response when big leaks occur at or below the surface. For ten years, Sandia has invested internal funding to develop and test new highly sensitive systems and sensors coupled with complex modeling that enable us to determine the attribution of specific emitters and emission types (e.g., combustion verses agriculture). We have also invested in optimization tools for stationary placement and moving monitoring tools to ensure the best configurations for a given cost burden. This work has primarily been pursued under LDRD investments but also in partnership with Lawrence Livermore National Laboratory, via projects funded by the DOE Office of Science, Basic and Environmental Research, and the power plant safety monitoring industry.

Waste gas utilization and conversation to useful products at the well head

Sandia researchers developed a modular, scalable chemical reactor platform, known as the Bayonet Reactor, that is capable of producing hydrogen and fertilizer products including

ammonia and urea. It works by first producing hydrogen from methane using a patented energy efficient steam methane reforming process. The hydrogen can then be used as a product or further reacted to produce ammonia (NH3) or urea (NH2CONH2). This technology resulted in a start-up company that could allow chemical companies to produce fuel and fertilizer in the same location as its intended uses such as farms or filling stations for hydrogen-powered vehicles.[3]

Related research that strengthens the nation's fossil energy related science includes:

Sandia has engaged in research related to deep geologic storage of various forms of nuclear waste for more than 30 years in our role as science lead for both the Waste Isolation Pilot Plant (WIPP) and the Yucca Mountain Project. The ability to characterize the subsurface, identify and mitigate risk, understand and communicate environmental and regulatory needs, and evaluate drilling and deep subsurface access, has expanded through this research with focus on multiple types of rock environments. Again, this broad set of research has fundamentally strengthened our ability to solve subsurface fossil energy challenges, understand wellbore integrity and induced seismicity, and support the Strategic Petroleum Reserve. Sandia continues to lead in developing the scientific and engineering basis for deep geologic disposal, and advancement of salt as a potential permanent disposal medium. Sandia is also a lead for enhanced geothermal energy production within the DOE laboratory system. In partnership with Lawrence Berkeley National Laboratory (LBNL) and other partners, we are pursuing deep crystalline rock fracking experiments at the Homestake Mine in South Dakota, which holds the promise of bettering our understanding of both geothermal and fossil energy control mechanisms.

SUBSURFACE SCIENCE IS COMPLEX AND REQUIRES INTEGRATION ACROSS BASIC AND APPLIED RESEARCH

Subsurface science deals with a wide zone from the Earth's Surface to nearly 10 KM below the surface and must address the coupled thermal, chemical, biological, hydrological, physical, energy propagation, and mechanical behavior of naturally occurring, significantly heterogeneous, and dynamic materials, ensuring integrated understanding and information across scales ranging from nanometers to hundreds of kilometers.

As we venture into this highly heterogeneous system, the most challenging problem is getting accurate in-situ data. In this case, in-situ means very high temperatures and pressures, often found in complex, inaccessible, and expensive environments. One of the key enabling technologies is material science and micro-electronics research to develop materials leading to sensors that can withstand these environments. Basic research focused on material science, additive manufacture, molecular scale water-rock interactions, metal and natural material interfaces and similar research pursued by the DOE Office of Science Basic Energy Sciences lays the foundation for the ability to capture the essential information to advance applied data collection tools.

Due to the critical importance these Earth systems play in all of Sandia's missions, Sandia has developed key capabilities to address and link these complex systems of systems with world-leading capabilities in geomechanical testing from nano to macro scales, subsurface access and sensing including microsystems, electromagnetic-seismic-infrasound sensing and interpretation, robotics and downhole tools, data structures, high performance computing moving toward exascale computing, and risk based decision making.

The efficiency, safety, and mitigation of environmental consequences will increasingly depend on highly skilled application of integrated sensing, analysis, and control tools. Sandia's approach to developing this next generation set of capabilities will be described later.

[3] https://www.abqjournal.com/1221553/bayotech-builds-its-first-modular-hydrogen-plant.html

SCIENCE THAT HELPS UNDERSTAND AND CONTROL THE SUBSURFACE IS APPLICABLE ACROSS MULTIPLE NATIONAL NEEDS

Subsurface research that is applicable to Oil and Gas production is equally valuable to enhanced geothermal production, understanding and implementing CO_2 sequestration, nuclear waste disposal, environmental restoration, basic research in geosciences, water resource management, and multiple national security needs.

> For example, the vast majority of the oil and gas we use comes from wells drilled using drill bits that incorporate synthetic diamond cutters known as polycrystalline diamond compacts (PDC). PDCs were invented in the 1970s and the promise of using this new material in drill bits was recognized by Sandia. With funding primarily from the DOE Geothermal Program and its federal predecessors, Sandia engaged in fundamental research, testing, and industrial partnerships to help develop a new bit for drilling through rock. Sandia's efforts catalyzed the commercial development of these faster drilling, longer lasting, advanced bits. Today, PDC drill bits are used in many subsurface applications including energy extraction, civil development, and mining. The shale revolution, the potential for enhanced geothermal energy and our science-driven deep-drilling programs would not have happened without the PDC drill bit.
>
> Studies have shown that Enhanced Geothermal Systems have the potential to unlock 100 Gigawatts (which could meet nearly 10% of U.S electrical need) of sustainable, electrical power capacity.[4] Sandia is one of nine national labs and numerous academic and industry partners working together on a DOE-EERE funded project called EGS Collab that will provide critical information needed to inform site selection for future large-scale geothermal facilities that can contribute toward US energy independence.
>
> The objective of the project is to perform small-scale reservoir model prediction and field validation experiments to understand the basic relationships between stress, seismicity, and permeability which form the critical technical barriers to achieving commercial EGS deployment.

It has been Sandia's objective to use knowledge gained in any one of these endeavors to benefit others and thus support our broad energy and national security programs/mandates. When the leadership of the Department of Energy works to integrate across these programs it greatly enhances technical cross-fertilization and results in game-changing solutions

The research pursued for fossil energy or geothermal purposes has benefited from and provides benefits to national security applications including combat drilling, Global Nuclear Test Detection, and understanding of nuclear weapons effects.

Additionally, this research helps our nation prepare for and respond to national emergencies. A few examples, from the recent past include:

> 2010 Deepwater Horizon: At the behest of then Secretary of Energy, Steven Chu, former Sandia Laboratory Director, Tom Hunter, was asked to lead a multi-lab team comprised of researchers and scientists from Sandia, Lawrence Livermore National Laboratory and Los Alamos National Laboratory. Hunter and the multi-lab team were asked to quickly stand-up a temporary laboratory to provide on-site support to BP and Secretary Chu as they wrestled, around the clock, to overcome the immense technical challenges required to stop the flow of oil in to the

[4] Massachusetts Institute of Technology (MIT). 2006. The future of geothermal energy. Cambridge, Massachusetts. Available: http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf.

Gulf of Mexico and to understand and mitigate the cascading effects of the explosion which tragically killed 11 people.
2015 Aliso Canyon Natural Gas Storage Methane Release: Sandia, Lawrence Livermore and Lawrence Berkeley National Labs were enlisted by the State of California to assist in dealing with the 2015 natural gas leak after a failed well resulted in the release of about 200 million pounds of methane into the atmosphere. Sandia and our partner laboratories worked together to support the State in evaluating options to stop flow from the well and, in the aftermath of the leak, to evaluate standards to mitigate future risks associated with natural gas storage. The Aliso Canyon event spurred a DOE-supported effort that examined well integrity associated with natural gas storage in aquifers and depleted reservoirs. This work was led by the National Energy Technology Laboratory and involved Sandia, Lawrence Berkeley and Lawrence Livermore National Labs.

An emerging national challenge is wellbore integrity detection, prevention, and remediation. Sandia has an established role as a leader in the field of wellbore integrity. In addition to managing the US Strategic Petroleum Reserve, for the last decade Sandia has developed a thriving R&D program in wellbore integrity that has produced novel materials to repair damaged wellbore seals, as well as new state-of-the-art predictive tools to identify "problem wellbores" prior to failure.

THE COMPLEXITY OF EARTH SYSTEMS MOTIVATES AND FACILITATES ADVANCES IN CUTTING EDGE RESEARCH

The Earth is our largest and most complex data set. While it is currently an analog data set motivating the strong "observational science" approach of most geoscience education programs, we are rapidly working to digitize or convert what we see into a numerical representation. For example, NASA's Earth Observing Data and Information System (EOSDIS) consists of a collection of data which is currently 22 petabytes (just over 16 billion floppy disks) in size. NASA estimates the volume of data in this one archive will increase to almost 247 PB by 2025. [5] This data volume represents just one Earth Science data set; however, there are several others. Big Data in many scientific fields is creating a new paradigm in which novel scientific discoveries are being made through the analysis of large data sets. As access to data increases and a digital view of the earth emerges, we will have the need and the opportunity to use all forms of data analytics, artificial intelligence, and physics-based computing to decipher its processes and value.

To this end, SNL is investing in a program known as Real-Time Subsurface Event Assessment and Detection (RESEAD) to enable a step-change in real-time, continuous monitoring connected to the analysis and decision-based management of the subsurface. This Smart Subsurface Sensing System will work with any subsurface access point, including new and retrofitted existing wells. We believe this will lead to "Real-Time" characterization and production data, controls and decisions, machine learning data analytics, advanced math, and utilize Exascale models.

THE NATION BENEFITS FROM UTILIZATION OF THE WHOLE OF THE NATIONAL LABORATORY TECHNICAL CAPABILITIES

The nation needs to utilize the full technical capabilities and investments embodied in the national laboratories.

The national laboratories in the Department of Energy complex are vital, agile, centers of knowledge and R&D excellence. We are honest and prescient stewards of scientific information in the interest of the nation. It is the primary goal of the national labs to undertake research that is in the national

[5] https://earthdata.nasa.gov/eosdis-cumulus-project

interest and that fills the critical gap of early stage research that is of such high risk industry is unwilling to pursue it, or where universities don't have the ability to effectively integrate across multiple disciplines. Thus, National Laboratory-led research should be focused on large, national scale research projects that require innovative, game-changing thinking and broad integration. Of greatest importance and the area where the support of committee members is most needed, is the urgent need to establish a mechanism that connects the capabilities across the whole of the National Laboratories, academia and industry to unleash the greatest of US technical power. The technical expertise and innovation required to tackle our nation's energy challenges will take the efforts and collaboration of ***all*** of the DOE's national labs. We encourage and invite the Department of Energy to continue to leverage not only Sandia but our sister laboratories to solve these complex challenges.

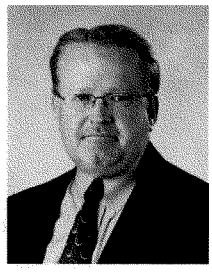
A recent example of the positive outcomes achieved through lab partnership was the Department of Energy's Subsurface Technology and Engineering Research, Development, and Demonstration (SubTER) Cross-cut. Under this program Sandia and several laboratory partners received funding through the Energy Efficiency and Renewable Energy (EERE)-Geothermal Technologies Office and the Office of Fossil Energy as national laboratory teams to work on cross-cutting topics relating to subsurface challenges identified across DOE programs. Adaptive Control of Subsurface Fractures and Fluid Flow was identified as the cross-cutting theme for the initiative. Another example is the Geothermal Technologies funded Collab research mentioned above.

By providing opportunities for the national laboratories to collaborate and work jointly with industry and academia on challenges relevant to both the nation and the Department of Energy, precious intellectual capital, which typically resides in the individual national laboratories in a siloed manner, were harnessed in a very effective way.

CONCLUSION

In conclusion, thank you again for the opportunity to provide testimony on the importance of Fossil Energy Research continuation. The research sponsored by the Department of Energy and in partnership with commercial industry and academia establishes the foundation for the US to remain energy independent, facilitates both our current use and expanded environmental management of fossil resources, and integrates our national security, renewable portfolio and basic science foundation. Sandia National Laboratories is proud of our heritage and the investments we have made to sustain our nation's subsurface energy science capabilities. We are energized by the challenge and complexity this field of science affords. It is essential our nation fully utilizes the capabilities and investments embodied in the national laboratories to meet these challenges.

Thank you for convening this hearing, and I look forward to your questions.



Erik K. Webb manages Sandia National Laboratories' Geoscience Research & Applications Group consisting of six departments: Geophysics, Geotechnology and Engineering, Atmospheric Sciences, Geomechanics, Geochemistry, and Geothermal Research. These departments engage across atmospheric monitoring and modeling, climate programs, fossil energy, geoengineering, nuclear repository programs, detection of underground structures, basic science of geological materials, geothermal energy, and geological elements of treaty verification and nuclear weapons programs for multiple federal agencies, foreign governments and in partnership with universities and commercial companies.

Erik has a MS and PhD in hydrogeology with emphasis in modeling and applied mathematics from the University of Wisconsin, has personally worked on an array of earth science problems with commercial (UNOCAL, STATOIL,) US Government agencies (USGS, ORNL, BOR, USACE, DOE, NRC, DOS, DOD and the EPA) and foreign government Agencies (Japan, China, Taiwan, Sweden, Switzerland). He served a fellowship with the Japanese Atomic Energy Agency, oversaw hydrological research at Sandia National Laboratories, served two years as a Congressional Fellow on the Senate Energy Committee and three years on the personal staff of Senator Pete Domenici focusing on western water policy and energy issues. Erik served as assistant to Sandia National Laboratories Chief of Staff, and as Government Relations Manager for the nuclear weapons program during ratification of the third START treaty with Russia. Just prior to his role in geosciences, Erik managed the Global Security Systems & Technologies Department working with Department of Energy non-proliferation programs, led the Second Line of Defense Program responsible for creating a nuclear detection network at international ports of entry in 50 countries, and led Sandia's DHS Borders and Maritime Security program working with DHS, Customs and Border Protection and the US Coast Guard. Erik was adjunct faculty in the Department of Earth and Planetary Sciences at the University of New Mexico providing lectures in Geoscience, Bioscience Decision Theory and worked with the Utton Center of the Law School on Western Water Planning.

Chairman LAMB. Thank you. We will now begin our first round of questions, and I will recognize myself for 5 minutes.

Ms. Burns, if I could start with you, you talked a little bit about the economic potential of carbon utilization in the growing market that we have. I believe you sort of implicated in your comments we have an example of it already happening in my district with the cracker plant that the Shell Corporation is building basically in order to create polyethylene out of the runoff from natural gas drilling. There was a note in the table in your testimony about polyethylene being an example of what you refer to as carbon tech.

So could you maybe address that in a little bit more detail about the economic potential that you see and how it's currently connected to things that are implicated in this bill? You know, what are the investments that we are making that may be likely to build on the progress we're already seeing in that space?

Ms. BURNS. Absolutely. We did a market-sizing report that I mentioned that showed that there's a $1 trillion total available market in the U.S. for this carbon tech—for carbon tech goods. And in particular, as you mentioned, we see opportunities in certain sectors. Building materials, chemicals and plastics, and fuels are, I think, three of really the biggest. There are also things like specialty materials. There's a startup near D.C. actually making carbon nanotubes out of captured carbon dioxide.

And though—this bill does I think a couple of really important things for the carbon tech industry. The first is it really ramps up the investments we make in these technologies. To date, we spend about $10-$12 million a year. A lot of that's really focused on algae applications. That's really great, big fans of algae. There's a lot more out there. And so scaling this up is going to allow us to support other applications of carbon dioxide and carbon tech.

The other thing it does is to scale up deployment of carbon capture and direct air capture technologies where we're going to have more feedstocks of captured carbon dioxide, there are already I think 80-plus projects here in the U.S. We have more than any other country in the world, and if we invest in these companies today, many of which are small-scale startups though there are some larger examples like you talked about, as well as LanzaTech and other companies, that we have an ability to take advantage of that and reap those economic benefits here in the U.S.

Chairman LAMB. I agree, thank you. And we've already seen great success at NETL with the development of new membranes, which is exactly the type of technology that if we develop here we would be able to sell probably anywhere in the world, so that's been great work by them.

This is a question for the group. It seems to me that a lot of the demonstration-scale projects in the power sector that have done in the past were done sort of before or during the early phases of the natural gas revolution, and many of them were focused on coal rightly. That made a lot of sense at the time. But we're in a new era that has happened very quickly. So if anyone is prepared to talk about the practicalities of a demonstration-scale natural gas plant with carbon capture, how soon we can get there, how our legislation or future legislation that we might do would impact that or help us, that would be very helpful.

Ms. ANGIELSKI. I'll start with this. One thing that I want to point out at least with post-combustion carbon capture is that it is a very—has a lot of broad applications among a variety of industries. So in the power sector it can have a broad application in both coal or natural gas applications, and then on the other industrial sectors that are covered in the other bill that you're looking at, it's really sort of the solvents that are inside the equipment that need some of these slight modifications that can be utilized among a variety of industry applications.

So it's important to note that I think that the Federal as well as the private-sector investments that are going into these technologies, no matter what the fuel type is that they're being designed for, are going to have a lot of applicability to other sources of natural gas or other industrial flue gases. I think where we are right now is that we need to take that research and we need to start testing it in other industries or more broadly across these other fuel sources. And I think——

Chairman LAMB. Yes. No, I agree with that, absolutely. I just think that when you look at the numbers, for example, of what it could do to the electricity cost coming out of a coal plant versus a natural gas plant, they might be very different. I think we would probably learn things along the way if we were able to demonstrate that.

The last point I wanted to make before I ran out of time was, Mr. Holstein, you did talk a little bit about methane detection and the prevention of leakage, and I wanted to commend the Environmental Defense Fund, which did some great work in the Pittsburgh area on our residential gas delivery system in detecting leaks. I think CMU (Carnegie Mellon University) and Google were a partner and actually drove all around the city of Pittsburgh to do that.

So can you describe maybe in just slightly more detail, and then I'm out of time, the way that our efforts in this bill will help us do that on a wider scale throughout sort of the lifecycle of natural gas as it comes out of the ground through the distribution network?

Mr. HOLSTEIN. Absolutely. And the two questions you've asked are clearly linked at least in my mind in that the best starting place is to stop the leaking we already know about. And the good news there is that the private sector has responded with the development of lots of new advanced leak detection tools that, according to one of the companies, are 1,000 times more sensitive in detecting methane leakage than they were just a short time ago.

Those tools are being mounted on vehicles, as we did in Pittsburgh and nine other American cities and will be rolling out in other cities around the world soon or they can be in drones or light manned aircraft. So there are multiple opportunities to put in place the technologies that can help decarbonize the oil and gas sector in significant ways using technologies that are available right now.

And, what do they cost? About a 40 percent reduction in methane emissions from the oil and gas sector can be cut right off the top using current technologies costing less than 1 penny per 1,000 cubic feet of gas produced annually. So these are definitely cost-effective technologies that are in the marketplace.

My description of the applicability of these bills to those challenges simply is that, as I said in my testimony, it's terribly impor-

tant that, as we move forward with any of the technology pathways that are discussed in the legislation, we have environmental guardrails, if you will, around that work. So for example, we have to monitor and keep track of what is potentially leaking into the atmosphere. If we sequester carbon, we need to be sure that it stays there, let's say in a geologic formation, and so these technologies begin to multiply in terms of their benefits as——

Chairman LAMB. Thank you. And I probably have to cut you off there to get to the other Members.

Mr. HOLSTEIN. Sure.

Chairman LAMB. Thank you very much. I now recognize Mr. Weber for 5 minutes.

Mr. WEBER. Well, Mr. Chairman, I would have yielded you another minute if you'd yield me 2. So I thank you, Mr. Chairman, for that.

This actually is for all the witnesses. We talk a lot about developing technologies to capture CO_2 from existing power plants, but we also know that the economics for capturing CO_2 won't work, and I can give you the ARA money spent on the air products CO_2 capture sequestration storage unit in my facility in my district in Port Arthur and some of the others. It's got to be in the right place, it's got to be close to a pipeline, it's got to have somebody that can use it. And of course the example we use most often is enhanced oil recovery. All of those factors have to fit.

So I'm aware that not every region has those kind of properties where all of this fits nicely together. So my question is what about the rest of the country? Is it carbon capture in the way we often think about it, or is it a new way of producing power like using supercritical CO_2 instead of steam? How do we make sure we're developing these truly kinds of revolutionary technology for the future across the country?

And, Ms.—

Ms. ANGIELSKI. Angielski.

Mr. WEBER. Angielski, I'll start with you.

Ms. ANGIELSKI. OK. Thank you. I think that it's important to point out that there are at least a number of storage reservoirs that we are blessed with geology in this country, and so those storage reservoirs are not just enhanced oil recovery reservoirs. And so I think that will help to expand our regional opportunities for actually siting some of these projects or the technologies even in the Midwest, I mean, in Ohio, in those regions there are regions where we have really good secure geologies that we can store CO_2 for millennia. And we're—and the DOE is actually working——

Mr. WEBER. For a millennia?

Ms. ANGIELSKI. Well, that's my word, but yes, for at least——

Mr. WEBER. A long time.

Ms. ANGIELSKI [continuing]. A very long time. And so—and then, you know, others on the panel can speak to—you know, as Erin has already pointed on some of the CO_2 utilization pieces of this but——

Mr. WEBER. Well, if I may, so would you be in favor of building a pipeline system that actually helped us transport that across the country for use, taking methane and CO_2 out of the air and actu-

ally sending it through pipelines to the various industrial areas where they could actually use it?

Ms. ANGIELSKI. So there are analysis—there is analysis that is looking at building some of those pipelines and some larger pipelines that they call trunk lines that could take the CO_2 from those industrial sources and actually move it to those storage reservoirs either through enhanced oil recovery or otherwise.

Mr. WEBER. OK. Let me go to you, Mr. Holstein.

Mr. HOLSTEIN. You know, that's a darn good question. A lot of the answer to the question about the need for a national pipeline network will be driven by the demand for, in this case, CO_2. I think it's more likely, as we sit here today—and others on the panel may disagree with this—but I think it's more likely that we're going to find other ways to use CO_2 if we're able to——

Mr. WEBER. So would you transport it by tank car or by 18 wheeler——

Mr. HOLSTEIN. Well——

Mr. WEBER [continuing]. Put more trucks or vehicles on the highway?

Mr. HOLSTEIN. Well, first, I would say that the markets are likely to develop regionally. In other words, if these technologies are applicable nationwide, there's no reason why we couldn't develop regional and even local markets for that CO_2 that is captured. And so we may not need a national network of pipelines.

Mr. WEBER. But would you agree the economy of scale for an area that's unlike Texas where we have a lot of refining on the Gulf Coast—for example, 65 percent of the Nation's jet fuel is produced in my district—it's a little more difficult than in some of the other States where you don't have that kind of industry to capture CO_2 whether it's out of the air or whether it's from a power-generating facility, which we have, which is in Pete Olson's district. And I've been there. It's a little more difficult for those more rural areas to really have a market for that, so how do you capture that CO_2 and get it to market?

Mr. HOLSTEIN. Well, I think under this scenario I was discussing I'm not necessarily talking about concentrations of petrochemical production but rather suppose you're capturing the CO_2 from power generation, as you just mentioned——

Mr. WEBER. Sure.

Mr. HOLSTEIN. There's no reason why that couldn't be useful, let's say, in the Northeast or the Midwest.

Mr. WEBER. But it's for enhanced oil recovery for the most part.

Mr. HOLSTEIN. And for enhanced oil recovery is exactly what I meant when I talked about——

Mr. WEBER. All right. So if they don't have——

Mr. HOLSTEIN [continuing]. Regional uses.

Mr. WEBER [continuing]. Oil wells up there like we do in Texas, there's not really much of a market, is there?

Mr. HOLSTEIN. Potentially in Pennsylvania if you're asking about enhanced oil recovery.

Mr. WEBER. Right. Well, I'm out of time, so I apologize to the rest of you.

So, Mr. Chairman, I'm going to yield back.

Chairman LAMB. Thank you. I recognize Mrs. Fletcher for 5 minutes.

Mrs. FLETCHER. Thank you very much, Chairman Lamb and Ranking Member Weber, who is my neighbor at home in Houston, so I have a similar interest in a lot of these issues. And of course I represent Texas' 7th Congressional District. I represent the energy corridor, and it is of course the heart of the energy renaissance that we've been experiencing over the last decade or so. And so a lot of these issues are really critical, and I think technology is a huge piece of our path forward, and carbon capture technology in particular.

So we've already touched on a couple of things that I want to follow up on and give some of you a chance to expand some of your answers with the time constraints. But I want to start first with a question for Ms. Burns. In your testimony you were talking about turning carbon capture into an asset, and I think it would be very helpful if you could just elaborate on that and also touch a little bit on the difference between—or kind of describe the technologies associated with the direct air capture, which I think is very different from what we've seen in these pilot plants, one of which is in Mr. Weber's district, and of course my other neighbor Mr. Olson, who has the Petra Nova plant in his district. If you could touch on those, I think that would be helpful.

Ms. BURNS. Absolutely. So to your first question about what we can do with the carbon dioxide once it's captured, you had a question about enhanced oil recovery and where these might be located. That's obviously where we see a lot of CO_2 utilization today. However, we think that there's a huge potential to create more markets for CO_2 in other types of applications. Right now, we do see some applications for things like beverages and food or some niche applications like greenhouses.

But we think that being able to—you can take these and turn them into things like fuel. So I would use an example. LanzaTech is a company that has a project here in the U.S. They actually recently flew—they partnered with I think it was—was it Virgin? To fly a plane from Florida to London on fuels made from captured carbon oxides. We have a huge opportunity there.

And a lot of these fuels compared with conventional gasoline, if you make them from—if you capture carbon dioxide with direct air capture, those fuels that you can create from that captured carbon dioxide can be as much as 90 percent less carbon-intensive than traditionally produced gasoline.

To your second question about technologies for direct air capture, there are a bunch of options. The one that we hear the most about is direct air capture. There are three leading companies right now, one of which is a U.S. company, and they have about 11 projects between them. And what this technology does is instead of carbon capture technology that's installed on a smokestack so at a power or industrial facility, you're actually able to take it from the ambient air.

So again to your point, where you're going to see these, you don't run into the same kind of challenges around geology, pipelines, enhanced oil recovery when you're thinking about direct air capture. You can actually site them in lots of different places.

And the other thing I would say—the last thing I would say is that there are three companies we're really excited about the work they're doing. There was recently a project announced that will capture half a million tons a year. That's huge. That's a really big deal. But we want a really robust ecosystem of companies in this space. We want more than three. We want more than three technologies. We want to help drive down the cost of innovation. And the provisions in this bill to create the carbon renewable program will help get us there.

Mrs. FLETCHER. Thank you. And I just have a quick follow up. You mentioned the three companies. So it seems like this is an opportunity for the United States to have a leading role. Who are the other companies or where are they located the companies that are working on this as well?

Ms. BURNS. Sure. So Global Thermostat is a U.S. company and they have a facility in Alabama I believe. Then we've got Carbon Engineering, which is a Canadian company, and then Climeworks, which is a company in Switzerland.

Mrs. FLETCHER. OK. Terrific. Thanks. And I also want to follow up and maybe I can just put this out to the panel for anyone who wants to take this on. But I think one of the comments that you made, Mr. Holstein, was about kind of the other ways we can use the carbon. And we heard a little bit from Ms. Burns about that. But I think one of the challenges that we've seen across the board is, for whatever these other uses are, how can we move this from sort of interesting ideas and technologies to something that is—how do we make it economic and something that is commercially viable so that we can start having this direct air capture or we can have increased CCUS activity given where we are now? How do we move that forward?

Mr. HOLSTEIN. Two quick answers, and I'm sure other panelists would have ideas. One is that's why we have provisions in these bills that emphasize commercialization. We've been too afraid of commercialization. When I say we, I don't just mean Congress. I mean the environmental community and others. We don't like the idea of choosing technology winners, but that's not what this is about. This is about identifying sectors in which we need to make a leap forward technologically speaking just as we did with the space program, just as we've done in health and medicine. And as I say in the very first paragraph of my testimony, this is a competitive economic race, not just a race against time as far as climate change is concerned.

So one part of the answer is we're going to focus more on commercialization and fund those activities, and number two, it's been great to see how Congress has come around on a bipartisan basis to fund organizations like ARPA-E that know how to move things from the workbench past the technology "valley of death" and into the marketplace.

Mrs. FLETCHER. Thank you very much, and I see I've gone over my time, so I will yield back. Thank you all.

Chairman LAMB. I recognize Mr. Cloud for 5 minutes.

Mr. CLOUD. Thank you, Chairman. I think I'm the third Texan in a row, so I appreciate you, Chairman, on hosting this important

topic, Ranking Member Weber. This is a very key topic certainly with national security, economic implications.

I come from Texas as well, and we have a very diverse energy portfolio with wind energy, oil, LNG all in our district, and so I really appreciate the fact that we can have some of the discussions that have gone on here, a real pragmatic, solution-oriented discussion in this Committee, and so I appreciate that, Chairman and Ranking Member.

Dr. Webb, I was wondering if you could talk to us—we just mentioned commercialization. How does Sandia encourage private companies to take on the commercialization of basic research applications? Your written testimony talks about the bayonet reactor and other projects. Could you expand on that?

Dr. WEBB. The basic approach to commercialization involves one of two processes. If we have identified something in the early research stage that's promising, we'll make an announcement—a public announcement, so there's fairness of opportunity—to U.S. industries to come and join us in that research process. And so we would then share that intellectual property between the U.S. Government and the industry, and they would at the end of that research process be experts in that technology. And that's an excellent sort of process we call cooperative research and agreement process.

Second, if we've made investments whether it's through DOE funding or through our internal lab-directed research and we have breakthroughs, we will go through a process of patenting that research and then again we make that available in a fairness-of-opportunity process. And there are a number of other tech transfer mechanisms that are used. Sometimes we would allow staff to go for a 2-year leave of absence to work for those companies to carry that research into application. And so it's really our objective to ensure it gets used, and we have multiple of those mechanisms to do that. So the examples in my testimony really are examples of individual technologies that have gone out, but embedded in there are these processes that allow us to do it.

Mr. CLOUD. Would you care to mention a couple of those projects that have been successful that you——

Dr. WEBB. Well, certainly, the one that I mentioned in my initial testimony, the PDC bits, we did not patent that, but that was done with industry, and now it's being used for 90 percent of the wells and holes drilled in the—on the planet. That's an extremely obvious successful example.

The bayonet technology that you brought up that I also mentioned is one that converts methane to farm fertilizers and other kinds of precursor chemicals. That's been commercialized. It's been transferred to small industry. There are wellhead-scale demonstration projects under our commercial process underway.

And then we've got this Memzyme technology, which is another one of these CO_2 capture technologies that's basically biomimetic. It's patterned after the wall of a cell in the human body, and that technology has been commercialized through a partnership with the University of New Mexico and is now getting put into application.

Mr. CLOUD. And could you speak to some of the work that the lab has done on carbon capture in underground reservoirs?

Dr. WEBB. So we have really two focal areas. One is to understand what happens to CO_2 when it is injected into the subsurface. It goes into pores, fractures and pores in the subsurface, but does it stay in a liquid form? Is it mineralized? Does it become permanent in that place? And a lot of that work was funded under the DOE Office of Science in a series of research projects, 9 years with the University of Texas, and that was very successful in producing a science base for what happens in the subsurface.

We're also part of one of the field demonstration activities where we're doing an enhanced oil recovery demonstration project in the Farnsworth Formation in the Panhandle of Texas. And that's allowing us to monitor the front or the movement of the carbon dioxide into the subsurface using geophysics and other tools to watch that process and understand where it goes and how long does it stay there, and is it captured?

Mr. CLOUD. I only have 10 seconds left, but let me just say I appreciate the work on practical solutions for an American solution. I thought that technology is more the answer than it is retreating to a pre-industrial age America, so I appreciate the work that all of you all are doing in this area. Thanks so much for being here.

Chairman LAMB. I recognize Ms. Horn for 5 minutes.

Ms. HORN. Thank you very much, Mr. Chairman, and thank you for holding this hearing, Mr. Chairman and Ranking Member. And thank you to the witnesses for being here.

I agree with many of my colleagues. This is a critical issue that we have to solve in a thoughtful, intentional manner.

Coming from Oklahoma, it may sound a little bit like Texas. We of course have a strong presence of diverse energy sources from hydrocarbon to natural gas, wind, and solar. And since 2005, we've seen in Oklahoma and other places, reductions in greenhouse gas emissions in part because of increased deployment of renewable energy sources, as well as less reliance on coal-fired electric generation, especially through the use of natural gas.

And this I'm going to open up to the whole panel is I'm curious for any of the witnesses what you see as the role of natural gas playing in this transition process to more renewable sources?

Mr. BOBECK. Thank you for that question. That's a great question. C2ES has convened an advisory committee of industry precisely because there's not a lot of talk about what the path forward for carbon capture and natural gas is. There's been such a great gain in terms of greenhouse gas reduction from fuel switching that some people want to rest and say, well, we're OK now.

Well, eventually, we will have to capture the emissions from natural gas for a variety of reasons. One of those reasons is it is a world market. The world will demand low-carbon fuel. So—or, excuse me, low-carbon power. So we've really been trying to focus on what are the answers for the path forward. One is obviously a reduction in cost, and that's what this bill before us today is all about. You know, the carbon capture program is aimed at lowering costs across the board. The other is building out a network of pipelines that will reduce the cost of transportation.

But, you know, again, we expect this all to begin to intersect in around the 2030 range, but it needs help. There are a variety of policies that you all should be looking at that can help it. And I'll leave it there.

Ms. HORN. Thank you very much. This question is for Mr. Bobeck and Ms. Burns. As you know—and this is follow-on from the first part of the question, that over half of our electricity generation in this country still comes from coal and natural gas. And even as the percentage of electricity from fossil fuel generations continues to reduce, we still have work to do to manage this transition.

So, as we do that, not only thinking about the environmental cost but also the economic cost and how we can incentivize this, I'm curious to hear your opinion about the realistic transition in technologies and the movement between these sources that it's going to take and what innovative ways that you might suggest that we look at as a Congress to help move this along.

Ms. BURNS. Sure, I'm happy to make a couple comments, and then I'm sure Shannon has some that are even more insightful.

So I'll tell you I think this bill is a very—is a really important first step. As you mentioned, a lot of the carbon capture research has been really coal-focused. As Jeff mentioned, this is operating off of an authorization from 2005. Our reality today is very different. Those kinds of—the robust R&D programs that we're seeing here are really important.

I think another provision that's really important in this bill or something else that's really important in this bill that goes to both of your questions about changing electricity mixes is that there are places in here were the Office of Fossil Energy also has to work with the Office of Energy Efficiency and Renewable Energy. And as we see more integration across different types of electricity generation, that type of collaboration across offices is really, really important.

The last thing I'll say and give Shannon time to talk is that policies like 45Q, that was really important. I think, you know, we—we are huge supporters of that. There are other policies like that, market-pull policies that can help the deployment of carbon capture in addition to R&D.

Ms. HORN. Thank you. And I only have a few moments left, so if anybody has a quick comment.

Ms. ANGIELSKI. I would just add that I think from a technology perspective, the need for flexible operations in the power sector is going to be increasingly more important with the growth of renewables, as you mentioned, on the grid. And by that I mean we need to have still dispatchable generation on the grid, but that can follow the load that is being provided by wind and solar. And so that is one of the critical areas of research that's identified I think in this draft bill that will be important for fossil fuel generation, which is still going to provide a significant amount of that electricity well into the 2040 timeframe, so——

Ms. HORN. Thank you very much, and my time is expired. I yield back.

Chairman LAMB. Thank you. I recognize Mr. Norman for 5 minutes.

Mr. NORMAN. Thank you, Mr. Chairman. I want to thank each of you for taking the time to come today.

Mr. Bobeck, I think in your earlier testimony you mentioned there are some industries like steel, cement, paper production that have no alternative to carbon dioxide emissions. With a demand for steel and materials—and I'm a general contractor. With steel and materials set to only increase, some companies like companies in our areas have made it a go to be carbon-neutral by 2050. To what extent is the Office of Fossil Energy exploring the application of carbon capture to industrial sources such as steel?

Mr. BOBECK. They've done some great work in this area, and that's why we all—I think everyone at this table is very bullish on the future of carbon utilization, especially for its application in those areas. One of the things we think about—you know, we've talked about building out large pipeline networks, but something carbon utilization does is help you in geographic areas that are more difficult to decarbonize. For instance, if you've got a cement plant, you don't have to necessarily build a pipeline 200 miles away to store it. If you can build some sort of utilization plant nearby, you can utilize that CO_2 right there so it cuts the cost of the transportation obviously, and it creates something of value. So it's a very, very important thing.

The FER&D program has led the way on many of these technologies, but it is very explicit in this bill, and we see that as something very important going forward.

Mr. NORMAN. OK. In line with that, how should the Office of Fossil Energy prioritize decarbonizing the industrial-sector emissions?

Mr. BOBECK. Well, we think it's critical. It's a little over one-fifth of all CO_2 emissions in the U.S., and, again, because there isn't a simple renewable solution, say, because these are intrinsic to the processes of making these products, it's very important to look at different ways of decarbonizing, for instance, pre-combustion decarbonization. We were talking about jet fuel before. It's very hard to decarbonize or to capture the carbon from jet fuel post-combustion. It's much easier to lower the carbon content pre-combustion. So we would say it's a very important thing, and we commend the Committee for actually having a bill that focuses on this.

Mr. NORMAN. OK. I've got 2 minutes, but quickly, I guess for all of you, the Department of Energy's Advanced Manufacturing Office has been a leader in increased industrial energy efficiency. However, it has not paid much attention to more transformative zero-emissions pathways. It's been recommended that the AMO (Advanced Manufacturing Office), FE (Fossil Energy), and other relevant DOE offices develop technology roadmaps that could help achieve these pathways with carbon capture being the main component. Do you agree with this strategy? And we'll start with you.

Ms. ANGIELSKI. So I obviously have not given that as much thought as you have, so I would say that there's always opportunities to leverage across the program offices within DOE and cross-fertilize their areas of expertise to get real and much better and more efficient results. So——

Mr. NORMAN. And we need your help on that, getting a roadmap on literally what to do because you're flying in the dark——

Ms. ANGIELSKI. Right.

Mr. NORMAN [continuing]. Unless you have specifics.

Ms. ANGIELSKI. Yes, I agree.

Mr. HOLSTEIN. And I might add, Congressman—as the Chairman mentioned I'm a former Chief of Staff at the Department of Energy, so I have enormous respect for the Fossil Energy Office and for the national labs that are playing such a key role in all this. And I would simply say that one of the things about the draft legislation that's so impressive is that it does encourage this broad look, but it also brings forward, as I say in my testimony, the very best expertise from outside the Department, in the form of an advisory committee.

The need for technology advice I think is terribly important. I think Congress needs it, too, which is why I'll throw in my 2 cents and endorse the legislative appropriations bill that the House has moved forward that would reconstitute the Office of Technology Assessment (OTA), which 25 years ago was doing a fabulous job of advising the Congress on technology matters, including the kinds of questions you were just asking. OTA needs to be reconstituted, and I think Congress is right to do that.

Mr. NORMAN. Thank you. I'm out of time. I wish we could've gotten to the others. Thank you so much.

Chairman LAMB. Thank you. I recognize Mr. McNerney for 5 minutes.

Mr. MCNERNEY. Well, I thank the Chairman, and I thank the witnesses this afternoon.

Ms. Angielski, I thought I heard you say that the U.S. leads in carbon capture and storage technology. Is that right? So what would be the economic benefits to the United States with that leadership by 2040?

Ms. ANGIELSKI. So I think that there are a number of different ways that you can look at the economic benefits. One of the more immediate would be through—carbon utilization has been discussed by many of the panelists, whether that's through additional oil production by putting CO_2 into enhanced oil recovery, whether it's through creating new carbon conversion and utilization markets.

I think it's through the manufacture of equipment, it's through additional new jobs that will be created through a new industry that will hopefully emerge in the near future. So I think that there's a number of different ways. And then of course if we can manufacture equipment that can be sold overseas in addition to selling more oil overseas, I mean, we can see some real improvements from just exports in GDP.

Mr. MCNERNEY. Thank you. Mr. Holstein, you said that significant safeguards are critical to CCUS. What might that look like? How would that be implemented, safeguards?

Mr. HOLSTEIN. Certainly. You need to use monitoring technology, which is now pretty commonly available, to ensure that you're not experiencing the leak of CO_2 into the atmosphere. It would defeat the whole purpose of all your efforts to remove CO_2 from the atmosphere if it just sneaked its way right back out again.

On detection technology—the Chairman referenced earlier the project that EDF has had in 10 cities. It's a different purpose, but from a technology standpoint, advanced leak detection is very cost-

effective. I'd be happy to provide to you, if you're interested in following up, examples of companies that are doing this kind of very sophisticated leak detection work now.

Mr. MCNERNEY. So that could be applied to CH_4 fugitive emissions as well then?

Mr. HOLSTEIN. Absolutely, is being applied to fugitive emissions from the oil and gas sector right now. And we need more of it.

Mr. MCNERNEY. That's—I should say—I should say so.

Mr. Bobeck, I thought I heard you say the cost of carbon capture and sequestration would be greatly exceeded by the cost of not doing it. Was I incorrect in hearing you say something like that?

Mr. BOBECK. I don't think I put it in exactly that way, but it depends on if you take all the societal cost into account.

Mr. MCNERNEY. So you agree that that's the case?

Mr. BOBECK. Well, you know, again, we're behind, and this is such an important technology if we hope to reach the 2-degree warming targets. And what I didn't address was if you take it out of the toolbox, it makes everything else more expensive.

Mr. MCNERNEY. OK. That's another way of saying it. Thank you.

Dr. Webb, I worked at Sandia National Labs in Albuquerque as a contractor for many years, so I appreciate the great work that you guys do there.

Dr. WEBB. Sure.

Mr. MCNERNEY. Could you describe what the subsurface carbon storage looks like chemically? What happens when you put carbon in the deep subsurface?

Dr. WEBB. So one of the things that happens is it bonds with or mixes with water in the subsurface and/or any other fluids—oil, gas—that may be in the enhanced oil recovery process. And then it—as it reaches certain pressures, it gets into a liquid form, the CO_2 does, and this becomes a caustic material. It has a tendency to dissolve things that are in there in mineral form. And so it's a very complex chemistry. And, as a result, you can have precipitation of minerals in various pores. That would potentially be a good situation because it creates something that's more permanent. Or you could have things that are—areas of the formations that you're pushing into that effectively become blocked by those and you can't access all the pores.

Mr. MCNERNEY. So is there a danger of contaminating groundwater then?

Dr. WEBB. Well, carbon dioxide by itself would not contaminate groundwater per se, and all of the formations that we've looked at as prospective sequestrationsites are much, much deeper than groundwater formations at this point. But in addition, in order for carbon sequestration to work, there has to be a caprock. There has to be something that holds the carbon dioxide in place, and that caprock would also be then the barrier between the lower sequestration and the surface water would be the groundwater systems.

Mr. MCNERNEY. If the Chairman will indulge me, are there a lot of sites like that around the world or is that a rare thing?

Dr. WEBB. The—one of the first parts of this carbon sequestration program was that the—was NETL did a national map of potential locations in the subsurface that would work for this particular activity, and there are a lot of potential sites.

Mr. MCNERNEY. Thank you, Mr. Chairman.

Chairman LAMB. Thank you. I recognize Mr. Casten for 5 minutes.

Mr. CASTEN. Thank you, Mr. Chairman. Thank you to our panelists.

In order to get the CO_2 down to where we are all safe as a species, I kind of divide all of our universe of things we have to do—we don't have a choice about—we have to do all three of these, put into three buckets. We've got the first bucket of things where we invest capital and then save money on energy. Renewables, efficiency, conservation, we will earn a return on that investment. It may not be a return we like, but we'll earn a return.

The second bucket is stuff that we have to invest capital in, and we may or may not earn a return, which I broadly characterize as R&D, right? We're going to do our best and hopefully, if we succeed, we move some things into that first bucket.

And then the third is that even if we do all of that and we stop emitting CO_2 tomorrow, we've got to get the atmospheric CO_2 down below 400 again, which means we're going to have to do a lot of air-side separation in some fashion or another, and that's going to be capital-intensive and it's going to cost a lot of money to operate.

And I take your point; the social cost of carbon is higher, so we have to do all three, but that's the hardest bucket economically.

For obvious reasons, let's focus on the two buckets in this panel, and I want to start with Mr. Holstein and Mr. Bobeck. It's always struck me that the hardest piece in the industrial space is that slate of industries that use fossil carbon as a reducing agent. Fertilizer production, cement, steel, silicon, we need those products to have the kind of lifestyle we want, but it's really hard to think of how to do that without coal and natural gas.

As you look at those sectors, are we doing enough? Are there technologies you're particularly excited about? And if we can't get those sectors decarbonized, what residual of carbon emissions are we looking at that we just have to deal with continuing to emit that level to maintain the current lifestyle that we have?

Mr. BOBECK. Well, I'm going to bring up something that is not within the jurisdiction of this Committee, and that's a carbon pricing system, which would spread the cost of carbon across the economy and help us decarbonize, you know, as a foundation building up. So that's the one thing I would like to bring up.

Mr. HOLSTEIN. That actually was exactly what I was going to say. It's the fourth bucket. And in my testimony I said we needed this overall economic framework putting limits on carbon emissions that ratchet down over time and putting a price on carbon. And the reason you need that is because that's the only way you can be sure that all of this R&D work and all of this deployment that we are seeing in noncarbon energy sources, for example, are actually going to get us where we need to go.

Mr. CASTEN. To——

Mr. HOLSTEIN. Below that 400 parts per million——

Mr. CASTEN. You——

Mr. HOLSTEIN. Yes.

Mr. CASTEN. You don't need to persuade me of the need to price carbon. That's fine. I do want to stay within the jurisdiction of the

Committee, though, because there are practical thermodynamic constraints that are jurisdiction over this Committee. There are market-structuring constraints that are subject to other committees. And in those fields like steelmaking, like solar, I mean, how do you make a solar panel without silicon? How do you convert quartz into silicon without coal? I don't know how to do that. And, you know, how do you make fertilizer without natural gas? I don't know how to do that. And my question for you is are we doing enough in those fields from an R&D perspective, and do you guys see a path where we will have those sorts of tools available, or do we have to assume that those sectors are going to be undecarbonizable?

Mr. HOLSTEIN. I think it's neither of those. I think once you send a strong signal from Congress, from the States, Governor Cuomo just yesterday with his announcement of a climate plan, you send a signal about where the country is headed and the need to develop these technologies and pass bills like the ones we're discussing today that push toward commercialization. You start creating demand for and strong signals to encourage the private sector to make the innovations to either change those products or perform the same functions of those products using different approaches.

Mr. CASTEN. OK. Well, with the minute or so I've got left—I want to believe you're right. I just get nervous when it's the innovation will save us when I don't see the technology path.

So if I can move to Ms. Angielski—I'm sure I'm saying your name wrong, and I apologize—and Dr. Webb, same question on the air-side capture. These technologies are thermodynamically going to be very large and going to cost money to operate. As you look at the technologies that are out there, if you've got to start picking some, are there some that are inherently going to be cheaper? And I'm staying on the economics for environmental reasons. The lower the cost it takes to lower the carbon, the more carbon we can reduce with finite resources, so I'm not for a second saying that economics trumps, but I want to understand in your expertise as we look at ways to pull CO_2 out of the atmosphere, are there technologies you're really excited about?

Dr. WEBB. A short answer from me, I think that the only way we'll do this efficiently is to follow biomimetic—biological processes, and so that's the source of research that we should be looking at.

Ms. ANGIELSKI. I would actually defer to Erin Burns on this question if I might do that because we focus on industrial flue gases——

Mr. CASTEN. OK.

Ms. ANGIELSKI [continuing]. And the capture from that source.

Ms. BURNS. Yes, so we think the economics are really important, too. I would say a recent Rhodium report had shown that without additional innovation just by learning by doing, with the current technologies from the three leading companies we have out there today, we might get as low as $46 per ton. That's not zero, that's not positive. That's still a really long way.

Mr. CASTEN. It's below the social cost.

Ms. BURNS. Exactly. And I think when we're talking about that, when we're talking about the scale of deployment for direct air cap-

ture and the timeline, we're looking at really large scale in the 2030 and 2050 timeline.

That's also why we're really excited about this bill. There's a lot of innovation to be done. Right now, the Federal Government has spent a total of $11 million ever on direct air capture. That is a drop in the bucket. We need a lot more. And the fact that this bill would establish the first-ever carbon renewable program is really exciting. It's also really well-funded.

I would also say to your earlier question really quickly, I think there's a lot of technology we're excited about, and I think part of the reason we're so excited about the industrial decarbonization bill in conjunction with a fossil energy bill is that it does open up—we haven't done a lot of industrial R&D.

Mr. CASTEN. Yes.

Ms. BURNS. It hasn't been on carbon capture. There's been less at DOE. And this bill would look at things like innovative renewables applications that could replace some of the heat from fossil fuel. Carbon capture is actually cheaper on some industrial applications. We see a lot of small-scale deployment in the U.S. on carbon capture, and a lot of that's in the industrial sector, so when you're talking about fertilizers.

I would also say that there are new and innovative ways to make some of these materials. Some of that's using captured carbon dioxide, but there are other pathways that aren't just the Portland cement pathway that could help reduce those emissions further. So that's all to say there's a lot of really cool stuff happening, but we need more R&D, and that's why we're really excited about these bills.

Mr. CASTEN. Thank you all. I'm drastically over my time——

Ms. BURNS. Sorry.

Mr. CASTEN [continuing]. But thank the Chairman for allowing me to extend.

Chairman LAMB. And last but certainly not least, I recognize Ms. Stevens for 5 minutes.

Ms. STEVENS. Thank you, Mr. Chairman. And great to be with you all here. It was actually great that my colleague from Illinois was going over because it was picking up with some of the things that I wanted to talk about. And actually let it be known for the record—I say this all the time about the Science Committee at our hearings—it's the Midwesterners who rule the roost here, so thank you to our Chairman, you know, from Michigan and, you know, delighted to be talking about this.

But just kind of picking up where we left off with Mr. Casten. OK, carbon capture, you make—you're all making a nice case for it. We're glad to hear about the legislation and what it means to you, but let's drill down a little bit further. Ms. Burns, you're talking about $11 million that we've invested, a drop in the bucket. How far behind are we? What happens in the aftermath with the carbon capture? Are we burying it? Is it producing another economic opportunity or technological opportunity for us?

Ms. BURNS. Absolutely. So the $11 million is specific to direct air capture. We've actually spent—I don't know the full number, but right now, we spend about $100 million a year on our carbon cap-

ture program. Still, we need more, and again, this bill pushes us in the right direction.

Once you capture that carbon dioxide, there are a couple of different things you can do with it. We think that if you deploy carbon capture and carbon removal at the scale that you see in climate models, the vast majority of that carbon dioxide you're going to need to store underground. And as—like Dr. Webb has said, we have a ton—we are blessed with a ton of great geology for this. We know how to do it. Also, carbon storage program at Department of Energy and the Office of Fossil Energy has done some great work with this.

The other thing that you can do and something we're really excited about is you can convert it into commercial products, and this is a new industry. We got some companies who are at the forefront, but we've got dozens of projects in the U.S. And I think right now we have an opportunity—there are more projects in the U.S. than any other country. I think with more R&D funding, more Federal support in the form of provisions like 45Q that we can maintain American leadership on this. We can really help develop this industry, and we can take advantage of a $1 trillion total available market.

Ms. STEVENS. Yes. That's what we talk about a lot here in terms of the Science Committee and our agenda, which is catalyzing new channels for economic opportunity, as well as addressing some of the larger challenges that stand before our environment.

And picking up also with Casten's comments about the fertilizer and some of the industries that scale, we obviously have a reliance and, you know, some ways a reliance that I'm proud of as a Representative from southeastern Michigan on traditional manufacturing materials like steel and concrete and aluminum.

And, you know, in terms of how we think about the investments needed to decarbonize the production of these materials, some of which rely on decades-old processes without putting these companies out of business, what's at play here? You know, how do we do that? Is it a grants program? Is it leveraging something through DOE? Is it something we can tie into the legislation, anything that any of you guys have thought about that you can weigh in here in terms of that?

Ms. BURNS. I would say I think there's been a lot of talk about—we use the term research and development, but we think that those questions around demonstration and deployment, later-stage work with the private sector is really, really important. The Office of Fossil Energy has done a lot of that, but there are companies like ArcelorMittal who is a steel company in the Carbon Capture Coalition. They are looking at projects for industrial carbon capture. The Steelworkers Union, all of these groups have been really involved.

And I think if we look at ways where we cannot just do that kind of lab-scale R&D, which is really important, but later-stage partnerships where we have cost shares between private companies and the Department of Energy, we've seen that catalyze technology deployment, and I think that's a really important piece of this, and we're glad to see it reflected in the legislation.

Ms. STEVENS. Yes. And, Mr. Bobeck, did you want to chime in here at all on any of this?

Mr. BOBECK. One thing I'd like to say about that particular issue is something in this bill we like very much is the focus on large-scale pilots. We've all heard of the valley of death, and so I think I said somewhere in my testimony that there's nothing worse than a project that doesn't get built after all this innovation and research goes into it. So it is very important in this bill we believe that there is interest in taking this through at least close to the commercialization stage.

Ms. STEVENS. Yes. No, that's great. And it's obviously also something, as we think about the mark that we want to make and as we're legislating, it's the built environment, right? So we're navigating within that.

I just led a big initiative on clean tech tax credits and getting that back rolling and what that means, and it's not that we're leaving industry.

So, Holstein, did you want to chime in? And, by the way, great background. We're delighted you're here. But did you have something you wanted to add?

Mr. HOLSTEIN. I think in the interest of time I think Jeff said it——

Ms. STEVENS. OK.

Mr. HOLSTEIN [continuing]. Beautifully. I would just add that Dr. Webb mentioned in the course of I think one of his answers that the national laboratories, not just his but most of them if not all of them, have programs in which they generate patents, work with the private sector, and even let their own researchers and scientists take leaves of absence to help commercialize the technologies that in many cases they spend years developing.

I also mentioned ARPA-E, and the Loan Programs Office at DOE. All of these things are moving us more in the direction of the late-stage commercialization that we really need and that other countries like China do just routinely, reflexively. We need to be less afraid of being accused of being, you know, industrial policy-focused, crazy people.

Ms. STEVENS. Yes. Thank you for chiming in. Thank you, Mr. Chairman. I yield back.

Chairman LAMB. I think at this point we'd be crazy not to do what you're saying, you know?

So, lastly, Mr. Foster for 5 minutes.

Mr. FOSTER. Well, thank you, Mr. Chairman. And I guess as one of those Members who did visit NETL just a few weeks ago, you know, it's just amazing. I worked for most of my career at a national laboratory, and yet there are these jewels scattered all around our country that certainly Congress is not as aware of as they should be. And they're doing all these great things. Just trying to understand the fundamental physics of combustion is a field which will have a huge benefit because, as I'm sure has been mentioned a multiple times, we're not going to stop burning fossil fuels anytime soon.

I'd also like to second the Ranking Member's endorsement of R&D into using supercritical CO_2 as the working fluid for a high-

temperature, high-Carnot efficiency method of generating electricity.

And so as one of the frontiers in fossil fuels is trying to deal with the high temperatures, which is, you know, obviously hard on materials but potentially very good for the efficiency. And so are we looking down all of the relevant, you know, caves of possible technology development along those lines? Because it's one of the ways of making fossil fuel combustion, you know, more efficient.

Dr. WEBB. Let me take that question, please, Congressman Foster. So the material science element of this Brayton cycle supercritical CO_2 energy conversion process is the focal point of a joint research program that's shared between the Nuclear Energy Office and the Fossil Energy Office in particular focusing on materials. And these are both metals and the sort of gasket seals and other things that are needed in the system that are eaten away by CO_2 at those pressures and temperatures.

If it's effective, then it provides not only a more efficient energy conversion process, but it also potentially removes the water demand for cooling. And that allows us then to move energy generation to different places in the country. And I know that you've held a water hearing—water-energy hearing here recently, and that would also address some of the concerns that were brought up in that hearing.

Mr. FOSTER. Yes. Yes?

Ms. ANGIELSKI. I just wanted to add that DOE actually has a pretty robust high-temperature and pressure materials program through the Office of Fossil Energy that they are working in a consortium with private-sector and public-sector interests. And through that consortium, they are about ready to undertake testing of components at these higher temperature and pressures, and so that way they can also move those materials into a phase where they can be kind of standardized and we can actually start using them in these either new technologies or more commercial applications. And that program is ever-evolving to look at some of these future applications of supercritical—when I say future I mean more near-term future but supercritical CO_2 cycles, whether direct-fired or indirect-fired cycles that we see as really promising to achieve those efficiencies that you're talking about.

Mr. FOSTER. Yes. It's also an issue—I guess right now in the horserace but when you separate out the nitrogen to throw it away, you know, whether you burn the carbon-hydrogen in with a stream of pure oxygen or whether you try to deal with it later, which is looking like the low-cost solution to that? And are there solutions to the very high temperatures that you come to when you burn in pure oxygen?

Ms. ANGIELSKI. So I—we don't want to pick winners and losers, but I will say from a promising perspective, they're—this—as Jeff mentioned earlier, the pre-combustion aspect of these new power cycles is really very appealing because you are dealing with nitrogen in a post-combustion capture more diverse—I'm sorry, low concentration source of CO_2. And that's really what the real difficulty is in carbon capture today.

So if you have these new process cycles where the carbon dioxide is merely a byproduct of that cycle or water along with it——

Mr. FOSTER. Right.

Ms. ANGIELSKI [continuing]. You're producing this concentrated source of CO_2 that you then can just do what you need to do with it. So from a cost perspective, that's clearly much more appealing.

Mr. FOSTER. Yes, but then you have to find a way to generate the oxygen for cheap.

Ms. ANGIELSKI. That's——

Mr. FOSTER. And that's one of the challenges. Are there any prospective improvements in the efficiency of oxygen plants to do that, or is that pretty much immature technology?

Dr. WEBB. I'm not in a position to answer that question. I'd have to——

Mr. FOSTER. OK.

Dr. WEBB [continuing]. Do my own homework.

Mr. FOSTER. OK.

Ms. ANGIELSKI. I would just add that DOE and a lot of the industrial gas separation companies are very much invested in looking at improvements in those technologies, and there are some other novel approaches to it that—such as chemical looping, for example, the different form of oxygen that is concentrated that you can put into a combustion chamber. So there are some innovative things that are taking place to look at other ways of providing that oxygen——

Mr. FOSTER. That's——

Ms. ANGIELSKI [continuing]. For combustion.

Mr. FOSTER. Yes. That's really wonderful. But you do actually have to, at some level, place bets and pick winners and losers, and it's difficult and you don't want to have too heavy a hand, but, you know, both Congress and you, you know, have to choose the most promising technologies to put your money on, and it's a problem that none of us can hide from. And it's nice to see, you know, really top-notch people working to make the best calls on behalf of the taxpaying public, so thanks. I'll yield back.

Chairman LAMB. OK. Before we bring the hearing to a close, I want to thank our witnesses again for testifying before us today.

The record will remain open for 2 weeks for additional statements from the Members and for any additional questions the Committee may ask of the witnesses.

The witnesses are now excused, and the hearing is adjourned. Thank you.

[Whereupon, at 5:15 p.m., the Subcommittee was adjourned.]

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