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OPPORTUNITIES AND CHALLENGES THAT EXIST FOR ADVANCING AND DEPLOYING CARBON AND CARBON-DIOXIDE (CO2) UTILIZATION TECHNOLOGIES IN THE UNITED STATES

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED SEVENTEENTH CONGRESS

FIRST SESSION

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CONTENTS

OPENING STATEMENTS

WITNESSES

ALPHABETICAL LISTING AND APPENDIX MATERIAL SUBMITTED

OPPORTUNITIES AND CHALLENGES THAT EXIST FOR ADVANCING AND DEPLOYING CARBON AND CARBON-DIOXIDE (CO2) UTILIZATION TECHNOLOGIES IN THE UNITED STATES

THURSDAY, APRIL 22, 2021

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The Committee met, pursuant to notice, at 10:05 a.m. in Room SD–366, Dirksen Senate Office Building, Hon. Joe Manchin III, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. JOE MANCHIN III, U.S. SENATOR FROM WEST VIRGINIA

The CHAIRMAN. We are here today to discuss carbon utilization, the innovative process of taking carbon and clear stream CO_2 from industrial and power plants and out of the air and around us and turning it into valuable products. This is innovation at work, and it is shifting our perspective on how harmful emissions can instead be harnessed and put to good use. And what a timely discussion, given that today is Earth Day, to talk about this intersection of climate solutions and economic potential. I look forward to hearing from our panel of witnesses about barriers to scaling up these opportunities and the ways that we can support the advancement and deployment of carbon utilization.

Congress has made significant efforts in recent years to support carbon utilization technologies and projects. In order to get CCUS deployed at the scale we need, it is critical that we invest in research, development, demonstration, and deployment of the entire CCUS value chain from capturing CO_2 from coal and natural gas power plants and industrial facilities, to utilizing or sequestering that CO_2. That is why the Energy Act contained over $6 billion in authorization for CCUS, including over $280 million specifically for carbon utilization, including coal-to-products demonstration projects and a new carbon utilization research center. As Chairman, I am committed to ensuring the implementation of those provisions. We need to couple these efforts with necessary modifications to the 45Q tax credit to really incentivize the deployment of these projects and advancing legislation like the SCALE Act, a comprehensive CO_2 infrastructure package that I was pleased to co-sponsor and happy to see included in President Biden's Infrastructure Plan.

Nearly all studies have examined the potential pathways to net-zero carbon by 2050 have found a need for significant amount of carbon capture and carbon removal. Dr. Birol of the non-partisan, International Energy Agency (IEA), has consistently said, CCUS could be the most critical technology for us to invest in to meet our climate goals. I am proud of the work that National Energy Technology Lab, NETL, based in Morgantown, West Virginia, is doing under the leadership of Dr. Brian Anderson, one of our presenters today, to lead the way in CCUS efforts in the development of technologies to use coal in new ways. So I want to welcome Dr. Anderson. I look forward to hearing more about the innovative work being done at NETL.

Carbon utilization has substantial economic and environmental potential and should be a key part of conversations around economic revitalization. By 2030, the CO_2 utilization market, sized for products like concrete, fuels and chemicals, has potential to reach over $800 billion. This would represent about seven gigatons of CO_2, equivalent to 15 percent of global emissions. In addition, the use of coal as feedstock to produce high value products is a promising field. These new uses for coal can produce products superior in quality and durability to conventional ones, including certain lightweight, high-strength building products and materials like carbon fiber. The demand for carbon fiber, graphite and graphene will experience double digit annual growth in the years ahead. These new uses for coal also have potential to provide new economic opportunities and revitalize traditional energy producing communities, who have been hit the hardest by the energy transition.

Ramaco Coal is leading the way in the development of coal-to-products. I look forward to hearing from Mr. Randy Atkins about the work that they are doing.

I am heartened by the commitment to carbon utilization shown by industry and research partners. I am pleased to welcome two of our witnesses who were involved in the Carbon XPRIZE, a five-year, global competition that challenged innovators to develop breakthrough technologies to convert CO_2 into high net value products. Teams across the globe participated and demonstrated the value of CO_2 in a wide range of products, including alcohol used in vodka and sanitizers, plastics and batteries and even toothpaste. Mr. Jason Begger is the Managing Director of the Wyoming Integrated Test Center which provided the U.S. site for this competition and Dr. Gaurav Sant is the Founder and Chief Technology Officer of CarbonBuilt, who just this week was announced as one of the two winners of the XPRIZE for their work to embed industrial CO_2 emissions into concrete, helping reduce the carbon footprint of concrete by more than 50 percent. So congratulations to Dr. Sant. I look forward to hearing more about your technology experience and the future opportunities for this breakthrough technology.

In closing, let me reiterate the tremendous potential of carbon utilization to support our environmental and economic objectives. We have an incredible panel of experts with us today who are directly engaged in developing these technologies, and I look forward to this conversation.

With that, I am going to turn to Ranking Member, Senator Barrasso, for his opening remarks.

STATEMENT OF HON. JOHN BARRASSO, U.S. SENATOR FROM WYOMING

Senator BARRASSO. Well, thanks so very much, Mr. Chairman. I am delighted to be here with these wonderful people who are going to be testifying and sharing their thoughts and ideas with us.

You know, the International Energy Agency has repeatedly stated that if the world is going to meet its goal in addressing climate change, we will need carbon capture, utilization and storage, period. Earlier this year the Executive Director of the International Energy Agency testified before this very Committee in this room that carbon capture is an extremely important technology for reducing carbon emissions. That is why I have been a long champion of carbon capture technologies. In 2008, I introduced a bill called the Greenhouse Gas Emission Atmospheric Removal Act. I did this along with former Chairman of this Committee, Senator Jeff Bingaman, a Democrat from New Mexico, who was Senator Heinrich's predecessor on this Committee. More recently, I have worked successfully with a bipartisan group of Senators, including Senator Manchin, our Chairman, to expand the 45Q tax credit for carbon capture, utilization and sequestration. Last year, along with a bipartisan group of Senators, we successfully worked to enact the USE IT Act. The USE IT Act supports carbon capture, utilization and sequestration technology. It expedites the permitting of important infrastructure like carbon dioxide pipelines. It helps researchers find commercial uses for captured carbon dioxide emissions.

Carbon dioxide emissions can be transformed to create numerous products, including clothing from carbon foams, carbon fiber, building materials like cement and concrete and even, as the Chairman mentioned, hand sanitizer. And of course, Wyoming is on the cutting edge of carbon capture research and innovation. In 2018, the State of Wyoming joined with several rural electric cooperatives to open the Integrated Test Center in Gillette, Wyoming. The Integrated Test Center provides space for research teams to test carbon capture, utilization and sequestration technologies. The Center gives these teams the opportunity to use carbon dioxide emissions directly from Basin Electric's coal-fired power plant in Gillette. I have toured the Center several times, always impressed by the projects underway at the facility.

Last summer we actually had a Senate Environment and Public Works Committee Field Hearing at the Center. After the hearing, research teams provided hands-on demonstrations of their groundbreaking work and one of those teams was CarbonBuilt, who is being represented here today and recently won the prize, as you just mentioned, Mr. Chairman, the XPRIZE. CarbonBuilt used captured emissions in its concrete manufacturing technology. It was a finalist for the Carbon XPRIZE, a research competition to drive innovation in carbon capture, utilization and sequestration technologies. And on Monday, the Carbon XPRIZE announced its winners and CarbonBuilt was among them.

Mr. Chairman, I will point out I got an email last night from Senator Whitehouse. He joined you and me and Senator Cantwell when we visited one of the teams that was working as well on doing exactly that form of research. They competed, and the team that is here today was the victor. So we have been following this closely, you and I have, along with Senator Cantwell, Senator Murkowski and Senator Whitehouse. We are delighted to have the founder of CarbonBuilt, Dr. Sant, who has joined us here today and congratulations, again, to you and your entire team.

You know, earlier this month a newspaper in Gillette, Wyoming, Gillette News Record, did a story called "Case study: Integrated Test Center has potential to be prominent in CO_2 research, breakthroughs." The picture as you will see, Dr. Sant, is of—you may not be able to see it, but I know you have seen it before—of Iman Mehdipour of CarbonBuilt walking into where the work has been done in Gillette at the coal-fired power plant and the carbon capture facility. The end of the article, the author, the newsman reports, "The world needs an important and often overlooked Wyoming natural resource—innovation." And that is what you and I have talked about, Mr. Chairman, the need for innovation in the work as opposed to regulation and taxation.

[The article referred to follows:]

Watching out for you since 1904

Gillette News Record

SATURDAY, APRIL 10, 2021 × $2.00 × GILLETTENEWSRECORD.COM

SHE'S A KEEPER

CCHS freshman goaltender leads state in saves in first year playing, C1

SUPERNOVA OF POTENTIAL

STAR program shows how to lead by example, B1

PRINCIPAL ATTRACTION

Barrasso visits Rawhide to celebrate Bahige, A8

Campbell County has fewest fully vaccinated in state per capita

By JAKE GOODRICK
NEWS RECORD WRITER
jgoodrick@gillettenewsrecord.net

Months into Wyoming's COVID-19 vaccine rollout, Campbell County lags behind all other counties in the state with its percentage of population fully vaccinated, according to the Wyoming Department of Health.

But despite the lower numbers, Campbell County Public Health Executive Director Jane Glaser said the county's rollout has improved since its low uptake rates in the early days of vaccination.

As of April 5, the Wyoming Department of Health reported that 9.67% of Campbell County's population has been fully vaccinated for COVID-19.

The county with the next lowest percentage of fully vaccinated people is Crook County, where 11.81% of its population has had two shots or the single-shot Johnson & Johnson vaccine.

Teton County leads the way with 30.21% of its

See VACCINES, Page A8

Wyoming vaccine supply

PFIZER AND MODERNA

- **First doses received:** 189,090
- **First doses administered:** 154,529
- **Second doses received:** 147,695
- **Second doses administered:** 110,136

JOHNSON & JOHNSON (SINGLE SHOT)

- **Received:** 13,100
- **Administered:** 7,880

Source: Wyoming Department of Health. Numbers are as of Thursday and exclude federal doses for Veterans Affairs, tribal and military facilities.

Man accused of trying to get alleged rape victim to recant

By NEWS RECORD STAFF

LOUIZ S. PENA

A man accused of raping and holding a woman captive faces another felony charge of intimidating a witness.

A preliminary hearing has been continued for Louiz S. Pena, 35, who has been charged with influencing, intimidating or impeding a witness, which carries a maximum penalty of 10 years in prison and a $5,000 fine.

Pena already has pleaded not guilty to three counts of first-degree sexual assault, two counts of kidnapping and five counts of strangulation of a household member, all felonies, and two counts of misdemeanor domestic battery.

He remains in Campbell County jail awaiting trial on those charges, which is scheduled to begin May 24.

He was arrested in March 2020 after he allegedly beat, strangled and anally raped a woman. Police learned of the incident after an anonymous tipster called to say that Pena was bragging to his friends in Casper about anally raping a woman and giving her two black eyes.

Police went to the woman's home to check on her and found her with two black eyes, bruises on her neck and head consistent with strangulation and numerous bruises on her body and head. She didn't want to talk to police initially, fearing retaliation from Pena.

See CHARGES, Page A8

News Record File Photos/Mike Moore

Iman Mehdipour of CarbonBuilt walks near infrastructure used to turn waste carbon dioxide emissions into concrete at the Integrated Test Center at the Dry Fork Station power plant north of Gillette last August. CarbonBuilt is one of 10 finalists in the NRG COSIA Carbon XPrize competition in the running for a share of $20 million that could soon be awarded to teams that best demonstrate ways to capture and reuse waste CO_2.

Case study

ITC has potential to be prominent in CO_2 research, breakthroughs

By GREG JOHNSON × NEWS RECORD MANAGING EDITOR
gjohnson@gillettenewsrecord.net

What may have seemed more like science fiction less than a decade ago could soon become science fact.

Solving the planet's carbon dioxide problem has become one of the most pressing global initiatives, if not also one of the most daunting as scientists and governments contemplate what can appear to be a task so herculean it can't be done.

That's where places like the Integrated Test Center and people like Gaurav Sant come in.

Sant is a professor at the UCLA Smueli School of Engineering and team lead for CarbonBuilt, one of five finalist research projects chosen to compete at the ITC for a share of $20 million in prize money to turn CO_2 emissions into valuable products, and fiction into fact along the way.

Solving enormous, life-changing problems is what inspires scientists like him, Gaurav said. A crucial part of that inspiration was realized at the ITC, attached to the Dry Fork Station gas-fired power plant about 10 miles north of Gillette.

CarbonBuilt finished its on-site testing near the end of last summer and continues to research and refine its technology while waiting for the XPrize winners to be announced. The 10 finalists in two tracks of the competition — five at the ITC and five at a gas-fired plant in Alberta, Canada — may soon learn if they've done enough to win. The winner in each track gets $7.5 million for the solution that captures the most CO_2 and turns it into the most valuable products.

The teams split another $5 million in prize money when they were named finalists in 2018.

For CarbonBuilt, that solution is infusing waste CO_2 into concrete to make cinder blocks and other building materials.

Because the ITC gives research teams access to large amounts of flue gas from the power plant, it offers a unique opportunity to show how technologies can scale to handle a high volume of CO_2 emissions, he said.

"Without access to facilities of that sort, we wouldn't be able to do what we do," he said. "It's really a foundational step to be able to demonstrate and move the types of (solutions) we have."

News Record Photo/Mike Moore

Bottles of hand sanitizer made from waste carbon dioxide emissions on display at the Integrated Test Center last spring.

While at the ITC, CarbonBuilt completed some very successful research, Gaurav said.

"We were happy with the concrete results we ended up with," he said. "The demonstration was a success for two reasons. It showed us the system actually performed much better than our expectations.

"It showed the technology works, and it also showed the economics of the process. It demonstrated economics of what we suggested all along as it works out at a much larger scale."

While in Gillette, the team made about 10,000 concrete construction blocks, or about 160 metric tons of product, what Gaurav called "a fairly large quantity."

While CarbonBuilt and many of the other XPrize teams already have other partnerships and plans to commercialize their technologies, Gaurav said the point isn't to win.

"I think the XPrize really forced us to take something that was essentially a research project and translate technologies into a larger (scale) and through a commercial lens," he said. "It's a change in the scientific mindset

See CASE STUDY, Page A7

WEATHER, A2
HIGH 64
LOW 28

HISTORICAL VIEW: Holocaust survivors use social media to fight anti-Semitism, A2

INSIDE
BLOTTER, A2
CLASSIFIEDS, D1-D3
REAL ESTATE, D1
OBITUARIES, A4
OPINION, A3
SPORTS, C1-C3

0 94922 92117 8

Senator BARRASSO. So these are great opportunities for coal-to-product technologies as well and we have someone to testify to that today. Raw coal can be mined, treated and refined to separate the carbon content and then used in high-tech, high-value products. These products include carbon fiber, activated carbon and graphene. Last year, Mr. Chairman, you and Senator Capito and I introduced the COAL TeCC Act, which stands for "Creating Opportunities and Leveraging Technologies for Coal Carbon." Our legislation directs the Department of Energy to initiate pilot programs to help bring coal-to-product technologies to market. So I am very pleased to see that key sections of our bill were enacted as part of the 2020 Energy Act.

Today, Mr. Chairman, we are going to discuss the opportunities and the challenges facing both carbon capture and coal-to-products technologies. So before we begin, I want to thank you for putting this Committee meeting together and I want to welcome Jason Begger, who is the Managing Director of Wyoming's Integrated Test Center. Jason has testified before the Senate several times, including at a Field Hearing at our Integrated Test Center last summer in Gillette. I would also like to welcome Randy Atkins, who is the CEO of Ramaco Coal. Randy is establishing a coal-to-products research facility in Sheridan, Wyoming. Finally, I want to thank all the witnesses for testifying and participating today and look forward to the conversation.

The CHAIRMAN. Thank you, Senator.

With that, I will finish the introductions here. We want to thank all of our witnesses for participating today, and I think it is going to be a very, very interesting and very informative hearing. It will be quite hectic today. We have some votes coming up, and we are going to be going in and out, but we are going to keep this alive and we will have people by WebEx and we will have Senators coming in too.

I want to introduce Dr. Brian Anderson. Brian is the Director of the National Energy Technology Lab in Morgantown, West Virginia.

We also have Mr. Jason Begger, the Managing Director of the Wyoming Integrated Test Center.

We also have Dr. Gaurav Sant, Professor of UCLA's Institute for Carbon Management, and Founder and Chief Technology Officer of CarbonBuilt, Inc.

And then we have also, Mr. Randall Atkins, the Chief Executive Officer of Ramaco Coal.

We will start today with Dr. Brian Anderson for his opening remarks.

STATEMENT OF DR. BRIAN ANDERSON, DIRECTOR, NATIONAL ENERGY TECHNOLOGY LABORATORY, U.S. DEPARTMENT OF ENERGY

Dr. ANDERSON. Chairman Manchin, Ranking Member Barrasso and honored Committee members, thank you for this opportunity to discuss advanced carbon and carbon dioxide——

The CHAIRMAN. Can you turn it up a little bit?

Dr. ANDERSON. ——utilization technologies today.

My name is Dr. Brian Anderson. I'm the Director of the U.S. Department of Energy's National Energy Technology Laboratory, or NETL. Our research and development campuses are located in Morgantown, West Virginia; Pittsburgh, Pennsylvania——

The CHAIRMAN. Brian, excuse me, on your mic, you are going up and down. If you get closer to your mic. Let's try it again.

We've got so far, but just start talking again. We'll see if we can control it on this end. We're trying to get your volume up a little more.

Dr. ANDERSON. Sure.

The CHAIRMAN. There we go. Now it is perfect. Perfect.

Dr. ANDERSON. Okay, perfect.

So our mission at NETL is to drive innovation and deliver solutions for an environmentally sustainable and prosperous energy future. We develop technologies to manage carbon across the full life cycle—and have for many, many decades—that enables environmental sustainability for all Americans. So today, I want to discuss our decarbonization technologies and the opportunities that exist for advancing and deploying carbon and CO_2 utilization technologies in the U.S.

First, I'll speak to our, NETL's, advanced carbon products research which serve to develop high-value products from coal, aims to support communities that are impacted by the energy transition, both in past and in the future and to help translate those skills that they have for advanced manufacturing jobs. We are converting coal into high-value carbon nanomaterials with the potential to reduce manufacturing costs and energy consumption while simultaneously improving performance. Coal is an ideal product, ideal for producing graphene type nanomaterials that can be used in electronics, composite plastics, batteries, water filtration systems and 3D printing materials. We have also used coal-based additives to improve the strength of cement and concrete materials by 15 or 30, 35 percent which can be used to reduce building cost and the volume of construction materials. Our R&D on emerging carbon-based building materials is necessary to renovate these materials as suitable for construction purposes, including ensuring compliance with the strictest health and environmental requirements for building materials for metals.

So a few of our partnerships. We're partnered with the University of Illinois at Urbana-Champaign and Ramaco Carbon, to use domestic coal to manufacture energy-efficient computer memory chips. This technology can be used to enable the next generation of artificial intelligence and machine learning and I'm sure you'll hear more from Mr. Atkins on Ramaco's work. We're collaborating with X-MAT in West Virginia to establish the utility of Coal-Derived Building Materials licensed from their partner, Semplastics, out of Florida. The University of Wyoming researchers are collaborating with NETL to develop coal-derived carbon building materials from Powder River Basin coal pyrolysis products. Two of the building components can contain more than 70 percent carbon have been proposed, their char-based concrete brick and another carbon-based structural unit. By the way, NETL has partnered with CFOAM in West Virginia to develop carbon foam panels and lightweight aggregates from coal at atmospheric pressure. There are coal-derived carbon foams that are being produced commercially via big batch processes at elevated pressure, primarily for the use in composite tooling applications for the aerospace industry.

And now I'd like to speak briefly about NETL's CO_2 conversion and CO_2 utilization research. Our carbon utilization research aims to develop technologies to transform CO_2 into valuable products in an efficient, economical and environmentally friendly manner. The emerging field of CO_2 utilization encompasses many possible products and applications: fuels, chemicals, food and feeds, construction materials, enhanced resource recovery, energy storage, wastewater treatment and many others. We have developed new catalysts that can use electricity to convert CO_2 and methane into chemical building blocks and energy carriers. These inventions can allow the development of modular reactors that can use intermittent renewable energy, renewable electricity, to produce carbon negative commodity chemicals. We are partnered with the West Virginia University, the University of Pittsburgh and Longview Power to develop and test at the laboratory scale an innovative technology to produce commercial quality sodium bicarbonate directly from CO_2 from coal-fired power plant flue gas. In Dr. Sant's testimony you'll hear about CarbonBuilt's process to develop concrete blocks using CO_2 from power plant flue gas without the need for the carbon capture step. It's been demonstrated by more than 1,200 hours of field testing at the Wyoming Integrated Test Center, represented this morning by Mr. Begger. We're also working with Acadian Research & Development in Wyoming to synthesize a catalyst for the process to reduce CO_2 to synthetic graphite.

As discussed in the intros by the Chairman and Ranking Member, full decarbonization of the electricity sector by 2035 will require a combination of renewable resources, energy storage and reliable no- and low-carbon generation to assure reliability and affordability in our electric sector. Dispatchable fossil energy with CCUS can play an important role in conjunction with grid-scale energy storage for grid reliability during the energy transition. Our carbon reducing technologies are critical to managing carbon emissions in industries beyond electricity such as oil refineries and facilities that produce hydrogen, ethanol, cement or steel. In addition to carbon reducing technologies, negative emission technologies such as direct air capture and storage or bioenergy with CCUS and mineralization will play a pivotal role in managing carbon in long-term. We've been developing plans for a Direct Air Capture Center for evaluating emerging technologies in direct air capture.

So in conclusion, science, technology and research are powerful drivers of innovation and sustainable economic growth. Thank you for the opportunity to discuss some of these cutting-edge innovations which have application within and well beyond the energy sector.

Thank you.

[The prepared statement of Dr. Anderson follows:]

TESTIMONY OF DR. BRIAN ANDERSON

DIRECTOR OF THE NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

BEFORE THE

SENATE ENERGY AND NATURAL RESOURCES COMMITTEE

ON

CARBON UTILIZATION

APRIL 22, 2021

Chairman Manchin, Ranking Member Barrasso, honored Committee Members, thank you for the opportunity to discuss advanced carbon and carbon dioxide (CO_2) utilization technologies today. My name is Dr. Brian Anderson, and I am the Director of the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL).

NETL's research and development (R&D) campuses are located in Morgantown, West Virginia; Pittsburgh, Pennsylvania; and Albany, Oregon. NETL also operates field offices in Anchorage, Alaska, and Houston, Texas. The mission of NETL is to drive innovation and deliver solutions for an environmentally sustainable and prosperous energy future, ensuring affordable, abundant and reliable energy that drives a robust economy and ensures national security, while developing technologies to manage carbon across the full life cycle and enabling environmental sustainability for all Americans.

The laboratory is strategically positioned to accelerate the development of technology solutions through strategic partnerships. NETL's vision is to be the Nation's premier energy technology laboratory, delivering integrated solutions to enable transformation to a sustainable energy future. This philosophy emphasizes robust, early-stage R&D collaboration with universities and our sister national laboratories, coupled with industrial and private sector partnerships. NETL's expertise allows technology concepts to mature through these partnerships and to be deployed in the marketplace while protecting the public interest.

NETL maintains nationally recognized technical competencies and collaborates with partners in industry, academia, and other national and international research organizations to nurture emerging technologies. NETL also actively implements R&D projects for DOE's Offices of Fossil Energy; Energy Efficiency and Renewable Energy; Cybersecurity, Energy Security and Emergency Response; and Electricity. The laboratory's research portfolio includes more than 1,000 research activities across all 50 states, with a total award value that exceeds $5 billion inclusive of private sector cost sharing of $1.3 billion.

Today, I will discuss decarbonization technologies and opportunities that exist for advancing and deploying carbon and CO_2 utilization technologies in the United States. DOE has been tasked with a critical role to serve the Administration's bold climate agenda in a way that creates jobs for all

Americans and improves American competitiveness globally. It has been tasked by Congress to develop innovative, cutting-edge carbon capture, utilization, and storage (CCUS) technologies from the bench scale at the laboratory into commercially deployable solutions. NETL is up for the challenge, and is a major national resource for scientific research, discovery, and development of new clean energy technologies. Those technologies will ensure America's energy security and prosperity.

NETL recognizes the number of products and investments in carbon utilization is growing and has advanced cutting-edge research to make this possible. Examples of products that can be generated from CO_2 or coal products are activated carbon, carbon fibers, graphite, graphene, carbon foam, fuels, chemicals, construction materials, rare earth elements (REEs), and life sciences materials. REEs and composites are needed for renewable energy technologies, like wind propellers. Other carbon-based products can be deployed at the nanoscale for applications from computer chips to medical devices.

The Administration's emphasis is to advance technology development that can help communities affected by the declining demand for fossil fuels. Coal utilization for advanced carbon products is a perfect example of a "pivot" that can create jobs. Whether the source is a CO_2 stream from an industrial process or from coal waste, carbon is a focal point of NETL research that aims to exploit its inherent properties to develop better, lighter, higher-performing materials for construction, aerospace, energy generation, medicine, and everyday products.

NETL's Advanced Carbon Products Research

In a transitioning domestic energy future, innovation is needed to extract the full economic value from coal, coal wastes, and coal by-products to provide economic opportunities for coal communities across the Nation. Advanced carbon products research at NETL is enhancing the value of coal as a feedstock and developing new, high-value products from coal. Research in this program focuses on using developing technologies that use coal and coal-byproducts for manufacturing high-value engineered carbon products.

NETL research on advanced carbon products is focused on two major thrusts: (1) Materials Discovery and Design, where methods are developed for the scalable production of engineered carbons from domestic coal, and the performance and costs of using these carbons in consumer products are evaluated; and (2) Market, Technoeconomic, and Environmental Analyses of Coal-Based Manufacturing Processes, where efforts characterize the current and future markets for coal-based carbon products, and leverage technoeconomic and environmental life cycle analysis (LCA) to evaluate the environmental performance and costs of new coal-based manufacturing processes.

NETL researchers are converting coal into high-value carbon nanomaterials with the potential to reduce manufacturing costs and energy consumption while improving the performance of electronics, batteries, cements, and other consumer products. Coal naturally contains graphitic and aromatic carbon structures that make it ideal for producing graphene-type nanomaterials. These nanomaterials can be used in electronics, composite plastics, batteries, water filtration systems, and 3D printing materials. Nanomaterials made from coal can bring material cost down significantly and make these materials more ubiquitous for use in consumer products.

NETL is also exploring pathways to design, develop, validate, and fabricate a prototype building using carbon-based materials derived from coal. NETL has used coal-based additives to improve the strength of cement and concrete materials by 15-35%, which can be used to reduce building costs and reduce the amount of construction materials employed. R&D of emerging carbon-based building materials is necessary to validate these materials as suitable for construction purposes including ensuring compliance with the strictest health and environmental requirements for building materials from metals.

NETL research to develop high-value products from coal aims to support communities impacted by reduced use of fossil fuels and to help translate skills for advanced manufacturing jobs.

Cutting-edge Research in Advanced Coal Processing

NETL is partnering with the University of Illinois at Urbana-Champaign and Ramaco Carbon in Wyoming to use domestic coal to manufacture energy efficient computer memory chips called memristors. Memristors are a new technology that can use graphene from coal to increase computation speeds and reduce the energy needed for computing. Coal-based memristor technologies are faster and more efficient that the current systems used in the electronics industry and will be used to enable the next generation of artificial intelligence, machine learning, and edge computing.

NETL is collaborating with X-MAT CCC in West Virginia to establish the utility of Coal-Derived Building Materials (CDBM) licensed from their partner, Semplastics. CDBM components contain at least 55% coal by weight. The project will result in a market-worthy design for a CDBM dwelling structure and achieve the performance requirements to meet insurance standards (seismic, fire, wind resistance) and those of the International Building Code (IBC).

University of Wyoming researchers are collaborating with NETL to develop coal-derived carbon building materials from Wyoming Powder River Basin (PRB) coal pyrolysis products. Two building components containing more than 70% carbon, most of which is derived from coal itself, are proposed: char-based concrete brick, and carbon-based structural unit. These construction products have the potential to be transformational from a cost-benefit perspective and can be scale-manufactured for use in residential and commercial buildings.

NETL is partnered with CFOAM LLC in West Virginia to develop methods for continuous production of carbon foam panels and lightweight aggregates from coal at atmospheric pressure. Coal-derived carbon foams are currently produced commercially via a batch process at elevated pressure, primarily for use in composite tooling applications for the aerospace industry. This method of production limits carbon foam to high-value, small-volume markets. The goal of this project is to reduce the cost of carbon foam manufacture by over 90% to open up much larger market opportunities in the construction, infrastructure, and other industries, creating meaningful demand for U.S. coal.

NETL's Conversion and CO_2 Utilization Research

NETL's carbon utilization research aspires to develop technologies to transform CO_2 into valuable products in an efficient, economical, and environmentally friendly manner. R&D activities address the challenges and potential opportunities associated with integrating CO_2 utilization systems with various power, industrial plants, or carbon capture systems such as waste heat integration, wastewater reduction, flue gas contaminant reduction, and reduced energy demand. An ongoing program objective is to make technologies applicable for near-term implementation. Developing advanced catalysts, reactor systems, and processes for more efficient conversion of CO_2 to valuable chemicals can provide a viable alternative to conventional manufacturing processes that increase U.S. competitiveness and create jobs in addition to decarbonizing industry.

Cutting-edge Research in Carbon Utilization

The emerging field of CO_2 utilization encompasses many possible products and applications: fuels, organic and inorganic chemicals, food and feeds, construction materials, enhanced resource recovery (e.g., oil, gas, water, and geothermal energy), energy storage, wastewater treatment, and others.

NETL has developed materials and methods to synthesize and demonstrate new electrochemical catalysts and microwave active metal oxide catalysts that use excess electricity to convert CO_2, methane and/or water into chemical building blocks and emerging energy carriers, such as hydrogen, carbon monoxide, and formic acid. These inventions will allow the development of modular reactors that use intermittent renewable electricity to produce carbon-negative commodity chemicals. Microwave reactors also provide process intensification that allows economically viable operation of traditionally energy intensive processes. For example, microwave dry reforming of methane to produce H_2 and CO consumes 22 tons of CO_2 for every ton of H_2 produced, whereas a traditional steam reforming process to convert methane into H_2 produces approximately 10 tons of CO_2 for every ton of H_2.

NETL is partnered with West Virginia University (WVU), the University of Pittsburgh and Longview Power, LLC to develop and test at the laboratory scale an innovative technology that uses select amino acids (AAs) to produce a commercial-quality sodium bicarbonate directly from CO_2 derived from coal-fired power plant flue gas. Preliminary studies at WVU have revealed that two AAs, glycine and alanine, can convert CO_2 into sodium bicarbonate nanofibers or flowers of nanowires. Sodium bicarbonate, commonly called baking soda, has applications in baking, cleaning products, and pharmaceuticals. An associated techno-economic assessment for scale up and a carbon lifecycle analysis is underway.

In a collaboration between NETL and the University of California, Los Angeles (UCLA), more than 1,200 hours of field testing was completed at the Wyoming Integrated Test Center (ITC), successfully demonstrating a process to create concrete masonry units (CMUs, or concrete blocks) using CO_2 from power plant flue gas without the need for a carbon capture step. The UCLA technology is helping to mitigate emissions through a unique carbonation process known as mineralization, which transforms gaseous CO_2 from power plant flue gas and other sources into stable carbonate solids that bind the components in the concrete. The resulting blocks can be used in the same construction applications as traditional concrete blocks made with Ordinary Portland Cement (OPC). The potential global waste-CO_2 product market for cements, concretes, asphalts, and aggregates has been estimated at $1.3 billion by non-governmental organization Carbon180.

NETL is working with Acadian Research & Development in Wyoming to synthesize a catalyst for the process to reduce CO_2 to synthetic graphite. The proposed catalyst is composed of metal particles supported on nanofibers, which protects against particle agglomeration and has a surface chemistry that resists coking. These characteristics translate to higher catalyst stability and allow for operation of a multi-stage reactor system to produce graphite on a variety of substrates. The catalyst monolith will be produced using an in-house, custom-built 3D printer extruder. Characterization of the catalyst and performance measurements on a small-scale will be conducted to validate concept feasibility. Finally, testing of the catalyst in a multi-stage reactor will be used to demonstrate graphite production performance and catalyst stability.

Decarbonization Technology Landscape

While decarbonization is underway to varying degrees in many parts of the world and in the United States, technology development is required to achieve U.S. decarbonization targets. In the near term, decarbonization involves CCUS, the removal of carbon from fuels and/or combustion product streams for use and/or permanent storage in geologic formations. Another approach is to focus on blue hydrogen (H_2), derived from fossil fuels or biomass waste in a carbon-neutral or carbon-negative manner, en route to the eventual goal of using renewables-powered electrolysis to get hydrogen from water. Hydrogen generated from water electrolysis via renewable energy is referred to as green hydrogen.

Full decarbonization of the electricity sector will require a combination of (i) renewable resources, (ii) energy storage, and (iii) reliable, no-carbon or low-carbon energy generation to assure reliability and lower cost.

Because renewable energy may be variable or intermittent, dispatchable fossil energy with CCUS can play an important role in addition to grid-scale energy storage for grid reliability during the energy transition. Legacy power plants suffer from reduced efficiency and need increased maintenance when used as backup power for intermittent resources. Adaptation of existing plants and development of technologies for new energy systems to increase their flexible use has been a chief R&D objective at NETL for the past several years.

Carbon Reducing Technologies

Carbon reducing technologies are critical to managing carbon emissions in a wide spectrum of industries, from fossil-fueled power generation to manufacturing and heavy industry—including oil refineries and facilities that produce hydrogen, ethanol, cement, or steel. CCUS can enable advanced power systems to adapt to changing operational requirements, such as the growing need for fossil-fueled power plants to be a source of load-following, demand-responsive electricity.

CCUS technology programs enable both existing and advanced power systems to move toward effective carbon management and will provide valuable solutions for a wide range of industrial producers of CO_2 seeking to control emissions. The valuable advances and scientific information developed through NETL's program and in-house research can be applied globally to inform technology development across a wide range of carbon management scenarios.

CCUS has many potential benefits and can be a cost-competitive option for managing carbon relative to other low-carbon sources of electricity and products. Carbon capture involves the separation of CO_2 into a pure stream and, in many cases, compression to a supercritical fluid (liquid phase for transport – supercritical for injection) for transport via pipeline. Industry has a rich history of CO_2 separation, although few large-scale CCUS power plants are currently in operation worldwide. Successful examples of carbon capture at scale have been achieved with government support and policy incentives. Challenges include, the increased capital and operating costs of carbon capture relative to comparable plants with unabated carbon emissions and the possible reduction in net generating capacity. Investments in transformative technology can help to overcome these challenges.

Negative Emissions Technologies

In addition to the carbon reducing technologies, negative emissions technologies (NETs), such as direct air capture and storage (DACS), bioenergy with CCUS (BECCS), and mineralization, will play pivotal roles in managing carbon emissions in the long term. NETs are one component of a portfolio of solutions to achieve net-negative CO_2 emissions (i.e., removing more CO_2 from the atmosphere than is emitted) to mitigate climate change. The impact of widescale NETs would extend beyond zero CO_2 emissions, so that the absolute amount of CO_2 in the atmosphere would be reduced. Types of NETs include enhancing existing natural processes to increase carbon uptake by trees, soil, and other "carbon sinks" (e.g., reforestation); using chemical or physical processes to capture CO_2 directly from ambient air for storage or utilization (e.g., direct air capture systems); using plant biomass (which takes carbon from the atmosphere) to produce energy and capturing and storing the emitted CO_2 (bioenergy with carbon capture and storage); and enhancing geologic processes that capture CO_2 from the atmosphere and permanently binding it with rocks and minerals (e.g., carbon mineralization and ocean alkalinity enhancement).

Key NETL Initiatives and Facilities to Advance Decarbonization

The **Science-based Artificial Intelligence and Machine Learning Institute (SAMI),** a key laboratory initiative established in 2020, combines the strengths of NETL's energy computational scientists, data scientists, and subject matter experts with strategic partners to drive solutions to today's energy challenges. The institute is leveraging science-based models, artificial intelligence, and machine learning (AI/ML) methods, data analytics and high-performance computing to accelerate applied technology development. The goal is clean, efficient, and affordable energy production and utilization. SAMI is supported by NETL's cutting-edge computational infrastructure, including the Joule 2.0 supercomputer, the WATT GPU-based cluster, and the Energy Data eXchange (EDX®). EDX is an online public and private research curation and virtual data platform developed by NETL to improve access to trustworthy data products across DOE and beyond.

NETL's **Reaction Analysis & Chemical Transformation (ReACT) Facility** supports energy conversion engineering efforts, offering researchers innovative tools to advance the science of chemical reactions. ReACT's groundbreaking capabilities enable researchers to develop transformative technologies such as microwave-assisted chemical conversion that can reduce overall system energy requirements, decrease overall costs, and lower targeted emissions for energy systems. This facility has equipped NETL researchers to push the boundaries of microwave chemistry research. NETL reactors are among the most advanced in the world; they have been used for collaborations with the University of Pittsburgh, West Virginia University, the Rapid Advancement in Process Intensification Deployment (RAPID) Institute, Malachite Technologies, and others.

NETL's **Materials and Minerals Characterization Center** enables (i) efficient advanced energy systems; ii) CCUS technologies, and (iii) effective processes to convert fossil resources to high value products. Materials characterization is a key element in the materials development research process. Characterizing natural (or geological) materials is also essential to further NETL's deep understanding of the interaction of natural materials with CO_2 (or H_2) needed to advance safe subsurface CO_2 (or H_2) storage and enhance resource recovery.

NETL has been developing plans to design, construct, house, and operate a **Direct Air Capture Center (DACC)** for evaluating emerging technologies in DAC. The DACC would target technologies that are above lab scale but below full pilot scale. The center will provide a unique set of infrastructures to evaluate emerging and promising technology at scales and conditions facilitating industrial acceptance, resulting in rapid maturation into the commercial sector.

Conclusion

Science, technology, and research are powerful drivers of innovation and sustainable economic growth. NETL's world-renowned research facilities and technology development programs comprise a comprehensive portfolio of technological solutions to keep CO_2 emissions out of the atmosphere. Through in-house research, partnerships with industry, universities, and other national labs – and of course, Federal investments – it will continue to drive the commercialization of products and processes that achieve U.S. and international decarbonization goals while supporting job creation and global competitiveness as the world's energy transition proceeds.

Thank you for the opportunity to discuss some of these cutting-edge innovations, which have applications within – and beyond – the energy sector.

The CHAIRMAN. Thank you, Dr. Anderson.

Next, we are going to hear from Mr. Jason Begger.

STATEMENT OF JASON BEGGER, MANAGING DIRECTOR, WYOMING INTEGRATED TEST CENTER

Mr. BEGGER. All right.

Chairman Manchin, Ranking Member Barrasso, members of the Committee, I appreciate the opportunity to speak to you today. My name is Jason Begger and I'm the Managing Director of the Wyoming Integrated Test Center (ITC) which is a private-public partnership between the State of Wyoming, Basin Electric Power Cooperative, Tri-State Transmission and Generation Association and the National Rural Electric Cooperative Association. The ITC is the largest post-combustion research facility in the U.S. and is located at Basin Electric's Dry Fork Power Station. It is important to remember that post-combustion technologies are not just for coal plants. They can be utilized at other industrial facilities such as cement plants and steel smelters. There's a significant need for these processes in non-energy applications. All ITC funding has come from the State of Wyoming and our utility partners. While we believe there's an important role for the Federal Government to play in advancing technology and we would welcome such a partnership, no federal funding has been utilized, although some of our research tenants have received DOE grants to conduct their projects.

CCUS requires both the capture of CO_2 and then permanently doing something with it to ensure it is not released into the atmosphere. The ITC is unique in that it can host both types of technologies. Two important considerations for CCUS technologies are the amount of CO_2 utilized and the cost of the process. For things such as EOR [enhanced oil recovery], geological sequestration and mineralization, the CO_2 rich flue gas generally only needs to be captured and compressed. Plus, they can utilize vast quantities. Other technologies can be much more expensive. CO_2 is a very stable molecule with a double covalent bond so for technologies needing to break apart the atom, this requires a lot of energy leading to higher costs. Nonetheless, all are important and we need many options to successfully utilize large volumes of CO_2.

As was previously mentioned, the ITC hosted the Energy COSIA Carbon XPRIZE, but we are also working on a joint project with the government of Japan and Columbia University taking CO_2 and fly ash to produce carbonates which have a variety of industrial uses. One application is silica which is used to create polysilicate, a critical component of solar panels. Currently, 80 percent of the global supply originates in a region in China with serious human rights concerns. It is possible we could use CO_2 from a coal plant to produce components for the renewable industry. While programmatic funding is extremely important, Congress also needs to provide the means to carry out these projects by supporting the places where research can occur. NETL and the National Carbon Capture Center are great research facilities but limited in size and DOE has been sending American developers with U.S. taxpayer funded grants to test in Norway because there is not a facility large enough to test in this country. The ITC can host larger projects at better value to taxpayers with some additional infrastructure. We have the perfect blank canvas. Now we need to fill it. There is no better place than Wyoming to conduct this type of research. We have the facilities, suitable geology, regulatory agencies with expertise in regulating CO_2 and a "get to yes" mentality toward permitting and supportive legislature and governor and last, public support for these types of projects.

Fourteen years ago, Apple released the first iPhone which came with four gigs of memory, a two-megapixel camera, no flash, no zoom, no video camera. Today's iPhone 12 has 512 gigs of storage, facial recognition, four cameras and HD video recording capabilities. Yes, today's CCUS technology is still evolving, but as we know technology gets better and less expensive over time. We need to think about energy technology as we do with the things we utilize every day and appreciate how early government support made them possible. Touch screen glass, a staple of today's smart phone was developed in the U.K. in the 1960s for air traffic control applications. GPS, canned food, microwave ovens, the Internet, microchips, vaccines and nylon are all items developed by federal research. Technology is apolitical and the U.S. can make its greatest impact by investing in the knowledge that can be utilized around the world. Technology is the best way to ensure these countries have access to power while meeting environmental goals.

I appreciate the opportunity to speak with you today, and I'll gladly answer your questions. Thank you.

[The prepared statement of Mr. Begger follows:]

Written Testimony Submitted to the United States Senate Committee on Energy and Natural Resources

Testimony on Developing and Deploying Carbon Utilization Technologies

Submitted by Jason Begger, Managing Director, Wyoming Integrated Test Center, April 22, 2021

Chairman Manchin, Ranking Member Barrasso and members of the Committee, I appreciate the opportunity to speak to you today about our carbon technology efforts in Wyoming. My name is Jason Begger and I am the Managing Director of the Wyoming Integrated Test Center (ITC), which is a private/public partnership between the State of Wyoming, Basin Electric Power Cooperative, Tri-State Transmission and Generation Association and the National Rural Electric Cooperatives Association (NRECA). We have also received various in-kind contributions and support from Black Hills Energy and Rocky Mountain Power.

The ITC is a post-combustion, flue gas research facility located at Basin Electric's Dry Fork Power Station near Gillette, Wyoming. It the largest facility of its kind in the United States, delivering over 20 MW worth of scrubbed flue gas to researchers testing CCUS technologies. The power plant provides flue gas to six small research bays, each capable of hosting tests up to 0.4 MW and a large test bay that can host two demonstration projects with a cumulative total of 20 MW.

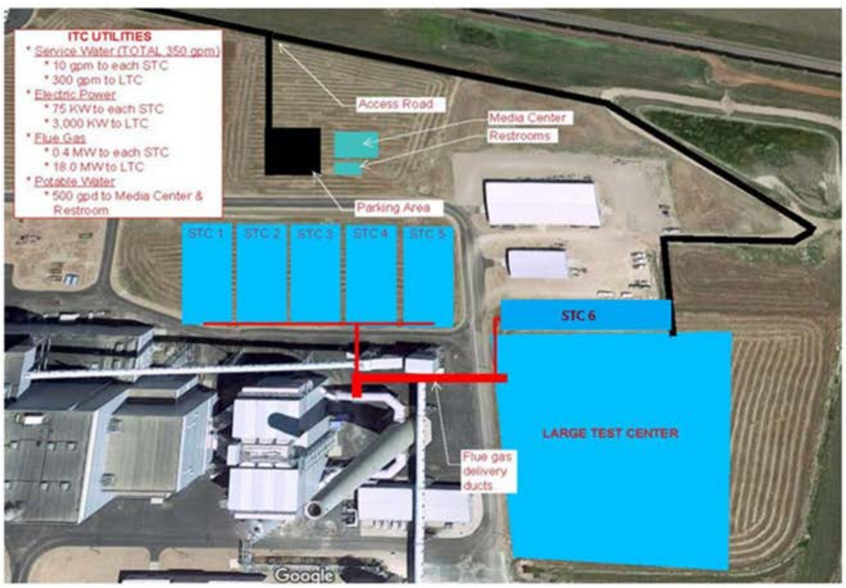

Fig. 1 – Site overview

To date, we have raised \$21 million in funding, \$15 million from the State of Wyoming, \$5 million from Tri-State G&T, and \$1 million from NRECA. While we believe there is an important role for the federal government to play in advancing technology and we would welcome such a partnership, not one cent of federal funding has been utilized in the costs of the facility, although some of our research tenants have received Department of Energy grants to conduct their projects on site.

Fig 2. – Small Test Bay tie-in

The State of Wyoming is the nation's largest coal producer, producing approximately 218 million tons in 2020. While this is still a significant amount of production, it is down from the peak in 2008 of 480 million tons. Given fossil energy's prominent role in the state, investment in carbon control technologies by Wyoming may seem unusual, but it all stems from an effort to move beyond the political rhetoric surrounding climate change science and focus on discovering technology solutions to ensure the long-term economic viability of Wyoming's fossil energy resources. It is important to remember that post combustion technologies are not just for coal plants, they can be utilized at natural gas facilities, cement plants and steel smelters. There is a significant need for these processes in non-energy applications.

The ITC is just one of several Wyoming programs aimed at commercializing next generation energy technologies. The University of Wyoming School of Energy Resources works on pre-commercial research; the Wyoming Pipeline Initiative is working to pre-permit corridors for CO2 pipelines; the Wyoming Enhanced Oil Recovery Institute researches the reservoir geology and is identifying carbon sinks for EOR opportunities and the Carbon Management Institute has active grants with the

Department of Energy to study permanent geologic sequestration. The Wyoming Energy Authority works to make the business case and integrate the various elements of diversified projects.

The one constant variable for all of these state entities is a push to commercialization. Every project needs to continuously track costs and economics, because without a demonstrable path to commercialization, all you have is an interesting idea. Strong partnerships with the private sector, especially those industries that would ultimately be a customer of the technology, helps ensure our research objectives are aligned with their economic needs. A great example of how this has been successful for Wyoming is the ITC Stakeholder Committee. This committee is comprised of representatives from major utilities who are involved in the technology evaluation processes for their various companies. These utilities are invaluable in determining the commercial appeal of a particular technology or process.

Fig. 3 – Overview of ITC connection to Dry Fork Station

CO2 management requires both the capture of CO2 and then permanently doing something with it to ensure it is not released into the atmosphere. The ITC is unique in that it has hosted both types of technologies. While work still needs to be done developing and commercializing capture technologies, we have seen commercial carbon capture projects on an array of industrial facilities across the globe. Today's commercial project largely utilize solvent technologies. Over the next few years, the ITC will be hosting research teams testing newer capture technologies such as dry sorbents and membranes with the goal of reducing capital construction and operational costs.

Wyoming has been utilizing CO_2 for Enhanced Oil Recovery (EOR) for decades. EOR is particularly useful because it provides an economic incentive through the production of oil and just as important, it utilizes large quantities of CO_2. The state is also home to a 10,000-foot test well under DOE's CarbonSAFE program. There's great promise that this site, which is located less than ½ mile from the ITC, will be able to permanently sequester CO_2 in the near future.

CO_2 is a very simple molecule, consisting of one carbon and two oxygen atoms. The array of products that can be created from oxygen and carbon is almost limitless. Fuels, plastics, building materials and carbonates are all examples. The opportunities for managing or utilization of CO_2 is expansive, however, the costs and opportunities can vary dramatically based upon how the CO_2 is used. For things such as EOR, geologic sequestration, biofuels, and certain mineralization technologies, the CO_2 rich flue gas can generally be used as is, it needs to be captured and compressed. Various other technologies can be much more expensive. CO_2 itself is a very stable molecule, created by a double covalent bond that requires a lot of energy to break apart the atom, so for technologies requiring this, they will likely have high energy inputs and operational costs that will necessitate a high-value product to make the system economical.

Another consideration is the amount of CO_2 being utilized. EOR, geologic sequestration, and mineralized CO_2 to make aggregate and concrete could can utilize vast quantities of CO_2. CO_2 to products will use far smaller amounts and, in some cases, CO_2 emissions far exceed global market demand for certain products. Nonetheless, all technologies are important, and we need all options available to successfully utilize large volumes of CO_2.

At the ITC, we do have experience with CO_2 utilization technologies. On Monday, the XPRIZE Foundation announced the winner of their five-year NRG COSIA Carbon XRPRIZE competition, which hosted the final round of the coal tract at the ITC. While COVID-19 travel restrictions prevented teams from China, India and Scotland from traveling to Wyoming, we did host two U.S. technologies studying concrete and chemical feedstocks. The ITC hosted the winner of the coal tract, CarbonBuilt, which utilizes CO_2 in concrete production.

We also have a project in the works with Japan and Columbia University, which will look at a technology developed for the steel industry and examine its applicability at a coal plant. It will use CO_2 from the plant and calcium from fly ash to produce calcium carbonates that can then has an array of industrial uses. One of the more interesting applications is making silica, which can be used to make polyciliate, which is a critical component of solar panels. Currently 80% of the global polyciliate supply comes from a region in China with serious human rights concerns. It is possible we could use CO_2 from a coal plant to produce raw materials for the renewables industry.

If fully funded, the programs authorized in December will go a long way towards advancing the full array of carbon management technologies. However, we need to make sure we do not forget that we need the facilities necessary to conduct that research. The ITC is primed to host these projects and could take on a larger role with additional infrastructure.

While programmatic funding is extremely important, Congress also needs to provide the means to carry out these projects by supporting the places where this research can occur. NETL and the National Carbon Capture Center are great examples of places doing research, but the U.S. critically needs places to test at larger scales. For years the U.S. Department of Energy has been sending American developers with U.S. taxpayer funded grants to Norway to test at the Mongstad test center because there was not a large enough test facility in this country. The ITC was constructed to fill that space, but still does not have all of the amenities the Norway facility can offer. We strongly believe that the ITC can fill an important role in commercializing CCUS technologies at a better value to the U.S. taxpayers with some additional investment. We have the perfect blank canvas, now we need to fill it.

Wyoming is the perfect place to conduct CCUS research. We have facilities, we have agencies with expertise in regulating CO2 and a "get to yes" attitude towards permitting, we have a legislature and governor supportive of technology development and lastly, we have public support for these types of projects. Within the last two years, Wyoming's budget has included over $25 million in funding to for CCUS research. If we are able to leverage those funds against DOE or other private sources, we have the ability to host some meaningful projects.

Fourteen years ago, Apple released the first iPhone which came with 4 GB of memory, a 2-megapixel camera, no flash, no zoom, and no video camera. Today's iPhone 12 Pro Max has up to 512 GB of storage, facial recognition, four 12-megapixel camera and HD video recording capabilities. Yes, today's CCUS technology is expensive and still evolving, but as we know, technology gets better and less expensive over time.

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

Technology is apolitical and the U.S. can make its greatest impact by investing in technology development that can be utilized around the world. There is considerable debate over the future of coal within the United States. However, every credible energy analysis from the UN Intergovernmental Panel on Climate Change to DOE acknowledges large amounts of coal will be used globally for the foreseeable future. Technology is the best way to ensure these countries have access to power yet meet environmental goals.

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

The CHAIRMAN. Thank you, Mr. Begger.

Next, we are going to have Dr. Gaurav Sant. I hope I pronounced that right, sir. I am sorry if I didn't.

STATEMENT OF DR. GAURAV N. SANT, PROFESSOR AND HENRY SAMUELI FELLOW, DEPARTMENTS OF CIVIL AND ENVIRONMENTAL ENGINEERING, MATERIALS SCIENCE AND ENGINEERING, AND THE CALIFORNIA NANOSYSTEMS INSTITUTE; AND FACULTY DIRECTOR, INSTITUTE FOR CARBON MANAGEMENT, UCLA; AND FOUNDER AND CTO, CARBONBUILT, INC.

Dr. SANT. Close enough, Gaurav.

The CHAIRMAN. Am I close?

Dr. SANT. Very close.

[Laughter.]

The CHAIRMAN. Thank you.

Dr. SANT. Of course. Chairman Manchin, Ranking Member Barrasso and members of the Committee, thank you for having me here today. There are five things that I want to really try and highlight.

Number one, of course, carbon dioxide utilization is really a key part of achieving our carbon reduction goals. This is foremost for its ability, not simply to provide a revenue queuing and a cost-effective pathway, but it's potentially one of the soonest pathways that we can really catalyze for carbon management. Second, when we think about really expanded investments, we have to think about expanded investment in carbon capture, utilization and storage across the entire life cycle, particularly I think what is important to highlight is to really place a special focus on grant-making mechanisms that support full-scale, commercial demonstration plants. These demonstration plants are needed, particularly not only to deal us technologies and retrain our workforce, but particularly to gain operational maintenance and production management experience with new processes and relevant skills. This is something that we've done on an extremely limited manner so far and this is something that needs to be greatly expanded. Importantly, this kind of experiential familiarity is extremely important to diffuse U.S. technologies across the world to enhance the competitiveness.

We've looked at the idea of transforming carbon dioxide out of concrete and this is really, in our opinion, an extremely effective approach for carbon utilization for a couple of reasons. Number one, the enormous scale of the construction industry, the relatively simple chemistry that's offered with this conversion and the permanence of immobilization. And I think this is something that we really want to highlight that when we think about carbon dioxide utilization, we want to think about permanence and the durability of immobilization as important aspects of carbon management. CarbonBuilt, a spinout company from UCLA's Samueli School of Engineering, is commercializing a technology of the sort that converts carbon dioxide into concrete and importantly, like Dr. Anderson just pointed out, it does it without a need for a carbon capture step. This work, you know, which has been funded by the Office of Fossil Energy's Carbon Utilization and Carbon Capture programs, is invaluable when we think about infrastructure renewal and infrastructure construction in the United States. And the reason is really simple because if we can enable construction at a really large scale with low carbon concrete, this is a significant and a catalytic means to create carbon dioxide utilization as a mainstream market opportunity.

Fourth, we want to think about strategic government actions and strategic government actions are really required when we think about how we would catalyze some of these markets. By strategic government actions, I'm particularly alluding to the need to ensure low carbon procurement and purchasing in the form of "Buy Clean" type of ideas, "Buy Clean" type of concepts, which look both at the cost and the carbon intensity of products and materials when we think about not simply construction, but the broad economy around us. In this regard, it's important to create incentives both for early-stage innovative companies and established corporations. Historically, we've looked at ideas like a tax credit and while a tax credit is a great way to offset a tax liability, for early-stage companies we need to look at concepts like a direct payment that's based on production capacity and production levels, really as a means to catalyze the sector.

Furthermore, when we think about carbon dioxide utilization, we need to really think about 45Q. And when we think about 45Q in the context of utilization we need to look at really reducing the cap on a qualifying project. The cap on a qualifying project, I think, on the order of law 25,000 tonnes, is simply too large and it needs to be reduced to a number on the area of about 2,000 tonnes to really make a difference for a utilization project. The reasons for this are really simple. We'll likely not achieve utilization in a small, delocalized manner across many different sites, close to consumption centers, aka, close to markets. It makes a lot more sense to have modular, smaller-scale plants which really are producing products and materials close to where they're going to be sold because this is what minimizes transport cost, particularly important when we think about commodity materials, you know, things like concrete.

The last thing I want to touch on is really a need for national databases. We lack national databases which have the tabulated data regarding the carbon intensity of materials and products and which follow, essentially, a rigorous review and standardized procedures for assessment of carbon intensity. This is important, not only for materials like concrete and steel and insulation materials, but it's important in general for products and services. These databases are important because they offer credible, technology neutral in an unbiased way to compare carbon efficiency intensity and improvements thereof which released, starts to give us an unbiased basis to rank and order materials and think about how incentives and credits could accrue as a function of the technology that's being deployed. Importantly, national databases of the sort are also important because they provide public transparency and an important part of what we're really thinking about is really allowing consumers and purchasers to make decisions about the products and the services that they would buy where if they wanted to buy low carbon products and low carbon services, they have the ability to consult a national database before making a purchasing decision.

With that said, I'd like to conclude, and I'm happy to take questions as we go further.

[The prepared statement of Dr. Sant follows:]

UNITED STATES SENATE: COMMITTEE ON ENERGY AND NATURAL RESOURCES

APRIL 22, 2021

HEARING ON: OPPORTUNITIES AND CHALLENGES THAT EXIST FOR ADVANCING AND DEPLOYING CARBON AND CARBON-DIOXIDE (CO_2) UTILIZATION TECHNOLOGIES IN THE UNITED STATES

WRITTEN TESTIMONY:

GAURAV N. SANT, PH.D.

PROFESSOR AND HENRY SAMUELI FELLOW: DEPARTMENTS OF CIVIL AND ENVIRONMENTAL ENGINEERING, MATERIALS SCIENCE AND ENGINEERING, AND THE CALIFORNIA NANOSYSTEMS INSTITUTE; AND, FACULTY DIRECTOR: INSTITUTE FOR CARBON MANAGEMENT
UNIVERSITY OF CALIFORNIA, LOS ANGELES (UCLA)

FOUNDER AND CTO: CARBONBUILT, INC.

INTRODUCTION: Thank you, Chairman Manchin, Ranking Member Barrasso and Members of the Committee, for inviting me to appear before you as you review and examine pathways for carbon dioxide (CO_2) utilization. I would like to start by emphasizing that the views expressed herein are my own.

As requested by the committee, I will focus the first part of my testimony on the need for carbon dioxide utilization. While not a direct solution to climate change in and of itself, carbon dioxide utilization will play a significant role in mitigating emissions from industry and other emissions-intensive sectors. Second, I will highlight pioneering research underway at UCLA's Institute for Carbon Management[1] that seeks to enable large-scale and cost-effective direct utilization (and removal) of carbon dioxide emissions, and thus accelerate our transition to a low-carbon world. In this regard, I focus particularly on the NRG COSIA Carbon XPRIZE-winning Reversa™ technology. This technology that transforms carbon dioxide-into-concrete was recently demonstrated at world-class test-centers in Wyoming and Alabama. Finally, I will elaborate on the support mechanisms that are needed to catalyze and accelerate the deployment of low-carbon technologies in the U.S. and around the world.

As background, I am a professor and Henry Samueli Fellow in the Samueli School of Engineering at the University of California, Los Angeles (UCLA), where I am the Director of our Institute for Carbon Management[1]. I am a civil engineer and a materials scientist by training, with broad competencies in materials synthesis, characterization and processing with special expertise in the materials of modern construction including cement, concrete, steel, glass and ceramics[2]. I am also the Founder and Chief Technology Officer of CarbonBuilt, an early-stage company which is commercializing the pioneering carbon dioxide-to-concrete technology developed at UCLA. Earlier this week, CarbonBuilt was announced as a Grand Prize winner in the NRG COSIA Carbon XPRIZE global competition.

In the testimony that follows, I will elaborate on the multiplicity of actions that are needed to advance and deploy CO_2 utilization (and more broadly, carbon management) technologies in the United States, including:

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[1] Institute for Carbon Management. UCLA ICM http://icm.ucla.edu/ (accessed April 17, 2021).
[2] Gaurav N. Sant. Google Scholar Profile https://scholar.google.com/citations?user=p_kytiYAAAAJ&hl=en&oi=ao (accessed April 17, 2021).

1) Expanded investments in research, development and demonstration of carbon dioxide management (e.g., including carbon-utilization, -removal, and -sequestration) technologies,
2) Explicit and flexible financial incentives to promote expedient industrial transformations, and
3) Strategic procurement actions which put cost and embodied carbon intensity of materials and products on an equal footing in federal procurement and purchasing decisions.

MOTIVATION: Industrial operations which result in the production of cement, concrete, liquid fuels, chemicals, steel, glass and other such materials, are foundational to the world that we live in. As the sources of materials that make up the automobiles that we drive, the buildings that we live and work in, and even the smart screens of our personal handheld devices, these operations affect and improve the quality of each of our lives, while contributing to the continuous development of our society. While foundational to our world, industrial activities are also a potent contributor to ongoing CO_2 emissions and atmospheric accumulations.

Industrial decarbonization is prerequisite to mitigating the ongoing accumulation and release of CO_2 into the atmosphere [N.B.: anthropogenic CO_2 emissions globally distribute in approximately equal thirds among heavy industry, transportation and the built environment]. However, such decarbonization on account of both being technically challenging and our societal dependence on these industries, needs to be implemented without disrupting the material contributions of these sectors to our way of life, or our cost- or standard-of-living. To meet these challenges, CO_2 utilization is expected to be the catalyst, and in other cases perhaps the only approach for achieving cost-effective decarbonization in the near-term. Therefore, it is important to stage, support and incentivize the deployment of CO_2 utilization technologies to help industry to transition from being a valuable contributor, but also a major CO_2 emitter, to only a valuable contributor (to society, and to our way or life) by 2050; if not sooner.

Compared to power generation and transportation, where the rapid worldwide deployment of renewable energy generation and storage assets is enabling emissions reductions, the decarbonization of heavy industry, which constitutes over a third of total emissions[3], is proceeding at a much slower rate. As a result, industry operations are emitting, and will continue to emit, substantial amounts of carbon dioxide into the atmosphere on account of their processing energy demands and the nature of chemical separations, modifications and transformations that they carry out. For context, chemical production, the production of ordinary Portland cement (OPC), and iron and steel production result in the emission of around 5 %[4], 10 %[4], and 9 %[4] of anthropogenic carbon dioxide emissions, respectively.

Heavy industry's reliance on fossil fuels is based on its need for high temperatures, high energy density[5], and/or predictable and continuous power[6] — requirements that cannot be met by renewable energy. While energy storage would help to address the latter issues, its substantial cost remains a significant barrier to adoption. Furthermore, in processes such as oil refining, cement production and others, feedstocks are broken down into simpler components before being re-composed into more chemically, and commercially desirable products such as gasoline and OPC. As a result, in such operations, a majority of the carbon burden is associated with the chemical route that is required/used. For example, in the case of OPC production[7] the thermal decomposition of limestone ($CaCO_3$) and the

[3] International Energy Agency. CO_2 Emissions Statistics https://www.iea.org/subscribe-to-data-services/co2-emissions-statistics/ (accessed April 17, 2021).
[4] International Energy Agency. Tracking Clean Energy Progress: Industry https://www.iea.org/topics/tracking-clean-energy-progress/ (accessed April 17, 2021).
[5] de Pee, A.; Pinner, D.; Roelofsen, O.; Somers, K.; Speelman, E.; Witteveen, M. *Decarbonization of Industrial Sectors: The Next Frontier*; McKinsey & Company, 2018; p 63.
[6] International Energy Agency; Cement Sustainability Initiative. *Technology Roadmap: Low-Carbon Transition in the Cement Industry*; World Business Council for Sustainable Development, 2018; p 66
[7] The production of ordinary portland cement (OPC) -- the primary binding agent used in traditional concrete – accounts for nearly 9% of global CO_2 emissions with 0.9 t of CO_2 being emitted per ton of OPC produced. Therefore, the development of new cementation agents that take-up CO_2 is critical to reduce the CO_2 emissions associated with cement/concrete production,

associated release of CO_2 (~65% of CO_2 emissions) is a far more significant contributor to emissions of the process than the combustion of fossil-fuels to heat the cement kiln (~35% of CO_2 emissions)[8].

Construction of industrial manufacturing facilities requires substantial capital expenditures and demands long capital-amortization periods. Since new capital investments may be difficult to justify in the absence of proven profitability, or the need to ensure regulatory compliance, it is critical that CO_2 utilization technologies readily integrate with existing processes, are energy efficient, and are subjected to transparent and time-bound permitting processes, if needed. Beyond the financial considerations, these additional issues are important to consider in terms of what is needed to accelerate the deployment of CO_2 utilization technologies.

DECARBONIZING HEAVY INDUSTRY AND THE BUILT ENVIRONMENT: Industrial decarbonization often implies carbon capture and storage (CCS)[9]. While CCS is expected to remain our primary path to address carbon dioxide emissions because of the potential scale it offers, its implementation is challenged by: (i) the high cost of capturing and concentrating carbon dioxide from flue gas streams, (ii) the potential uncertainty associated with the permanence of sequestration, (iii) the lack of reservoirs near current sources of carbon dioxide emissions, (iv) the absence, and cost of pipelines to transport carbon dioxide from sources to viable reservoirs[Error! Bookmark not defined.],[10],[11], and (iv) a lack of a clear liability-release or -cap, in jurisdictions where Sovereign guarantees have not been offered, that would limit the liability of project developers in the event of unexpected carbon dioxide release. This is especially relevant for the low-margin industrial sector, which is not well-equipped, financially or otherwise, to implement capital intensive transformations in an accelerated manner.

In contrast, carbon dioxide utilization can play an important, and immediate role in mitigating emissions, albeit in part, because of the absolute amount of CO_2 (on the order of a few gigatonnes) that could be utilized[12]. This is because the sale of products made using CO_2 has the potential to produce revenue, and conceivably yield a profit unlike typical carbon management solutions which imply an increase in cost, and hence reduction in profit. Timely action to mitigate the effects of climate change requires the rapid deployment of technologies for carbon dioxide utilization. The deployment of such technologies, like many nascent industries, will initially require government support to facilitate first-of-a-kind, commercial-scale demonstration projects that will inform our learning curves, demonstrate the commercial value-proposition, drive cost-reductions, and thus hasten follow-on deployments and adoption. Today, support for such demonstration projects, e.g., via grant-making mechanisms, is unfortunately very limited; but it is absolutely necessary. Industry has little ability to deploy unproven technologies at scale due to uncertainty in revenue and profit, substantial regulatory and compliance burdens, and the very high costs associated with emplacing greenfield facilities with long operating horizons. Therefore, it is necessary for the government to help mature, and de-risk technologies at large-enough scales to help heavy industry to reduce their carbon emissions (i.e., the embodied carbon intensity: eCI) of their products and processes. Combined with streamlined permitting processes, industry is expected to adopt change once they are assured of the commercial viability and scalability of new technologies. This will facilitate and simplify the market penetration, and widespread adoption of novel CO_2 utilization technologies.

[8] International Energy Agency; Cement Sustainability Initiative. *Technology Roadmap: Low-Carbon Transition in the Cement Industry*; World Business Council for Sustainable Development, 2018; p 66.
[9] In traditional carbon capture and storage (CCS), CO_2 emitted from industrial processes or from the combustion of fossil fuels is first concentrated to >95 % purity, following which it is transported by pipelines to locations that it can be geologically disposed, e.g., in hydrocarbon depleted reservoirs, saline aquifers, etc.
[10] Kulichenko, N.; Ereira, E. *Carbon Capture and Storage in Developing Countries: A Perspective on Barriers to Deployment*; Energy and Mining Sector Board Discussion Paper, No. 25; World Bank Publications, 2012.
[11] Bachu, S. *Energ. Convers. Manage.* **2000**, *41* (9), 953–970.

Furthermore, it is critical that the government greatly and systematically expand and harmonize basic and applied research, development and demonstration (RD&D) funding — within a unified framework instead of across disconnected programs and agencies (e.g., recent reports developed by the National Academies[12],[13]). With the ability to accept both successes and failure, harmonized support is needed to develop new technologies, and to scale-up and scale-out existing technologies for carbon emissions mitigation — the need for which becomes ever more significant with the passage of time[14]. Major programs for the development, de-risking and deployment of CCUS (carbon capture, utilization, and storage) technologies supported by the Departments of Energy, Defense, Transportation, Housing and Urban Development, and the National Science Foundation are critical in this regard. Such support is needed to: (a) maintain and expand the U.S.'s intellectual leadership in carbon management, (b) ensure that U.S. corporations, big and small, are able to diffuse and monetize their spirit of creativity, innovation and societal welfare globally, (c) ensure that U.S. corporations are able to diminish the carbon-intensity of their operations, thereby enabling them to operate – without constraint – across global jurisdictions in a low-carbon world, and (d) ensure that the U.S.'s deep intellectual reservoir housed within its universities, national laboratories and corporate R&D organizations continues to train, sustain, support and grow the talented scientists, engineers and subject matter experts that have ensured the U.S.'s global technological leadership and spirit of innovation over the last century.

Comprehensive actions to reduce CO_2 emissions from industry will require capital spending — by governments and corporations. For corporations however, a commitment to making capital expenditures, requires policy- and regulatory-certainty. Our current state of regulatory (and policy) uncertainty hinders our collective capability to limit the emissions of CO_2 into the atmosphere. The reasoning is simple: first, corporations which are required to create value for shareholders are only going to make decisions that ensure a competitive advantage in the marketplace in order to enhance shareholder value. Therefore, unless CO_2 emissions are constrained, penalized, or reductions thereof incentivized (e.g., via tax-credit, grant-, or cash-payment programs or a carbon emissions cap[15]; a penalty on unbounded excess; and/or limits on the embodied CO_2 footprint of manufactured products); there exists no driver, regulatory-, or compliance-based to make capital investments that would reduce carbon emissions. While consumer demand and investor pressures are forcing companies to make emissions reduction (and carbon-neutrality) pledges, often these pledges are a target rather than a binding commitment. To address this inertia, government purchasing decisions that prefer low-carbon products can catalyze market demand, especially for concrete, steel and other construction materials for which public entities are major purchasers. Such low-carbon procurement ("Buy-Clean") actions should be implemented promptly to affect supply chains both upstream and downstream, from the points of raw material procurement and manufacturing to the point of consumption.

All of us, i.e., society in general, are consumers of the products that industry manufactures. As such, an important aspect of carbon management involves affecting consumer choices, selections and awareness regarding the products that we seek to consume. As evidenced by our implementations of building energy-efficiency programs, this requires us to develop a national basis of measuring, affecting and incentivizing carbon-efficiency, and lowering carbon-intensity and -footprint via robust, progressive and transparent methods of data reporting and analysis, e.g., within national and sub-national databases. Why? Small, although quantifiable changes made by and demanded by 330 million consumers in the U.S. and 7 billion consumers globally could result in vast emissions reductions that are motivated by a combination of "industry-push" and "market-pull." Therefore, data disclosure and reporting initiated by

[12] National Academies of Sciences, Engineering, and Medicine. *Gaseous Carbon Waste Streams Utilization: Status and Research Needs*; The National Academies Press: Washington, DC, 2018; p 254.
[13] National Research Council. *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration*; The National Academies Press: Washington, DC, 2015; p 154.
[14] Mercator Research Institute on Global Commons and Climate Change (MCC). Remaining carbon budget https://www.mcc-berlin.net/en/research/co2-budget.html (accessed April 17, 2021).
[15] Nunez, F.; Pavley, F. *Assembly Bill 32 - California Global Warming Solutions Act of 2006*; 2006.

governments that creates consumer awareness is foundational to effecting broad-based industrial transformations, i.e., a market-driven basis of change. At this point, it should be highlighted that low-carbon products and construction materials can particularly play a major role in the American Jobs Plan, which heavily focuses on the built environment and U.S. infrastructure. For this reason, a federal "Buy Clean" procurement policy focused on reducing the embodied carbon footprint of our buildings and infrastructure would be catalytic in creating market demand for low-carbon concrete and construction materials, in general.

It is particularly important to highlight that issues related to carbon management are based on the premise of ensuring societal good. This is an outcome in which, the government, more than any other actor has a vested interest. Therefore, it is necessary that governments take the foremost actions. In this regard, the U.S. plays a special role in the international arena. This is because over the last century, the U.S. has come to be regarded as the bellwether for the world; such that actions implemented by the U.S. are examined closely and often followed by other governments. Of interest, the U.S. contributes nearly 15 % of global CO_2 emissions, while hosting only 5 % of the world's population[16]. For reasons of leading by example, it is essential that we place an emphasis on robustly maximizing our carbon efficiency, and in turn, diminishing our CO_2 emissions.

UTILIZATION – TURNING CARBON DIOXIDE INTO CONCRETE: Earlier this week, the UCLA CarbonBuilt team was selected as one of two Grand Prize winners of the NRG COSIA Carbon XPRIZE. This accomplishment, the first XPRIZE won by a university team, is a testament to: 1) the talent hosted within, and the spirit of innovation that is foundational to, U.S. universities, 2) the sustained support of our sponsors and partners, and 3) the potential of the concrete construction sector to serve as an enormous sink for carbon dioxide emissions. While multiple pathways exist for transforming carbon dioxide into products such as plastics, fuels, chemicals, concrete emerges as the foremost choice on account of both its large market size which translates into an enormous capacity to serve as a permanent carbon dioxide "sink" and the simplicity of the chemical conversion, or "mineralization", of carbon dioxide into concrete.

Even before the start of the NRG COSIA Carbon XPRIZE competition, our research at UCLA has been focused on developing cost-effective technologies that can directly transform dilute-state CO_2 (as borne in the flue gases of cement plants, power plants, etc.) into construction materials and products. Now being commercialized by CarbonBuilt Inc., a company spun out of UCLA, the Reversa™ technology avoids the need for "carbon capture" step, resulting in the lowest-cost pathway for scalable CO_2 utilization, while creating construction materials that are cost-, performance and function-equivalent to traditional concrete. Significantly, CarbonBuilt's solution produces concrete materials and products with an embodied carbon intensity (eCI) that is up to 75 % lower than the incumbents[17,18,19,20,21]. Furthermore, the low-carbon concrete products produced using CarbonBuilt's Reversa™ process are compliant with existing construction codes and standards and so are immediately suitable for use in construction projects. At this time, the Eastern Shoshone Tribe of the Wind River Reservation in Wyoming, and UCLA, among others, are in the midst of using CarbonBuilt's concrete masonry units in their construction projects.

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[16] Our World in Data. CO_2 emissions per capita vs GDP per capita https://ourworldindata.org/grapher/co-emissions-per-capita-vs-gdp-per-capita-international- (accessed April 17, 2021).

[17] Vance, K.; Falzone, G.; Pignatelli, I.; Bauchy, M.; Balonis, M.; Sant, G. *Ind. Eng. Chem. Res.* **2015**, *54* (36), 8908–8918.

[18] Wei, Z.; Wang, B.; Falzone, G.; La Plante, E. C.; Okoronkwo, M. U.; She, Z.; Oey, T.; Balonis, M.; Neithalath, N.; Pilon, L.; et al. *J. CO_2 Util.* **2018**, *23*, 117–127.

[19] Mehdipour, I.; Falzone, G.; La Plante, E. C.; Simonetti, D.; Neithalath, N.; Sant, G. *ACS Sustain. Chem. Eng.* **2019**, *7* (15), 13053–13061.

[20] CarbonBuilt Inc.: https://www.carbonbuilt.com/ (accessed April 17, 2021)

[21] The production of solid carbonates including calcite and magnesite exploits favorable thermodynamics and produces stable mineral reaction products that are known to persist at ambient temperature and pressure, without risk of CO_2 leakage, or release over billions of years. Furthermore, the handling of solid mineral carbonates, i.e., as compared to fluid-state CO_2 is simpler and therefore presents distinct advantages.

The development of CarbonBuilt's Reversa™ technology would not have been possible without the longstanding support of the U.S. Department of Energy's Office of Fossil Energy (and our philanthropic, and corporate partners), particularly its Carbon Capture and Carbon Utilization Programs. This support, which was provisioned to UCLA via the National Energy Technology Laboratory allowed us to demonstrate the technology at the Integrated Test Center in Gillette, Wyoming in 2020 and the National Carbon Capture Center in Wilsonville, Alabama in 2021. While these pilot-demonstrations have de-risked our solution from a technical standpoint, and helped ascertain the favorable unit economics of production, more work remains. Particularly, what remains now is to demonstrate our technology at commercial scale, a throughput level that is nearly 20 times higher than our current scale. Such commercial demonstration is needed to develop industrial comfort and experience in operating, maintaining and managing new technological processes that are somewhat different from those in use today. These are key activities for the broader industrial sector to gain confidence in low-carbon technologies. Given industry and investors' traditional reticence to participate in first-of-a-kind projects, strategic government support of initial commercial-scale projects can very significantly accelerate commercialization of promising carbon utilization solutions. Beyond just enabling the first deployments of new technological solutions, early-stage support could also involve direct incentives in the form of tax credits related to carbon dioxide utilization (and reduction), grants for energy efficiency improvements for plants that integrate CO_2 utilization technologies, or even penalties for ongoing, long-unabated and 'far-above-average' CO_2 emissions. These approaches, collectively, will serve to create both a domestic manufacturing base and a market for low-carbon products and processes.

THE ROLE OF SUPPORTIVE INCENTIVES AND MARKET MECHANISMS: It is necessary to develop structures and systems that incentivize CO_2 emissions mitigation by both early-stage companies, who seek to transform the industrial sector, and by established corporations. In this regard, reducing and reversing carbon dioxide emissions requires the development and broad-based deployment of technology-neutral incentives. Examples of current incentive mechanisms include the 45-Q tax credit[22], California's low-carbon fuel standard (LCFS)[23] and the Buy Clean California Act. These mechanisms, which offer incentives/credits up to $50 per ton (45-Q[22]), or up to $180 per ton (LCFS)[23] offer a means to offset the cost of CO_2 abatement technologies. On the other hand, Buy Clean mandates create a means for public works and other government agencies to incentivize (select or limit) the purchase of materials and products based in part on their embodied carbon intensity. While these are unquestionably steps in the right direction; more inclusive incentives are needed. For example, tax credits are valuable only if the developer has a tax-liability that can be offset. This advantages large established corporations over innovative start-up companies. Offering cash payments in lieu of tax credits, either for the construction of production capacity, or the production of products, would resolve this issue. In addition, even with the reductions enacted in 2018, 45-Q still requires 25,000 tonnes of CO_2 to be sequestered or utilized per year at a given site. This level is far too high for many of the most promising CO_2 utilization technologies, particularly those that are decentralized in nature. Reducing the cap to 2,000 tonnes per year, for example, while enhancing the value of the tax credit/cash payment for initial demonstrations of a particular category of utilization solution, could go a long way towards facilitating new decentralized approaches, i.e., which require proximity to markets rather than to simply large point-sources of carbon dioxide. As a prominent example, these types of progressive actions helped to ensure the success of both community and grid-scale solar power generation in the U.S.

Expansive thinking, in terms of incentive mechanisms and the consequent market forces that they could unleash, is needed to support the creation, adoption and diffusion of new carbon dioxide utilization technologies and the economic opportunities that are prerequisite to achieve rapid CO_2 mitigation. But

[22] Office of the Law Revision Council. 26 USC 45Q: Credit for carbon dioxide sequestration https://uscode.house.gov/view.xhtml?req=(title:26%20section:45Q%20edition:prelim) (accessed April 17, 2021).
[23] California Air Resources Board. Low Carbon Fuel Standard Program https://www.arb.ca.gov/fuels/lcfs/lcfs.htm (accessed April 17, 2021).

this requires credible, unbiased, and defensible publicly available data related to the (embodied) carbon intensity of products, services and processes that are sold in the marketplace. Thus, and in closing, it is critical to establish a national database that quantifies and tabulates the "carbon intensity" of both raw materials and finished products, e.g., for cement, steel, concrete, concrete products, insulation materials, glass, etc. This nature of database which does not currently exist would offer a credible, technology-neutral and unbiased basis to compare and incent carbon efficiency, intensity and improvements thereof, to develop low-carbon product standards (e.g., for concrete, and other construction materials) and to assess and accrue incentives in a transparent manner. Having such a basis of comparison would allow us to rank and order materials, products and services and create a means by which consumers and purchasers, i.e., the market could make informed product selections; thereby favoring the widespread adoption of CO_2 utilization technologies, and the low-carbon products that they are used to create.

Thank you again for the opportunity to testify on this important topic.

The CHAIRMAN. Thank you, Doctor.

Next and finally, we have Mr. Randall Atkins.

Randall?

STATEMENT OF RANDALL W. ATKINS, CHAIRMAN AND CHIEF EXECUTIVE, RAMACO COAL

Mr. ATKINS. Senators of the Committee, it is an honor to appear before you today and I would especially like to thank Chairman Manchin and Ranking Member Barrasso, who are both from two states that I proudly call home, as well as where our companies have their operations.

Coal today is basically thought of as a cheap, controversial, environmentally challenged fuel combusted in power plants. We look at the commodity, however, through an entirely different lens in which it has a higher value purpose beyond energy; one, frankly, where coal becomes too valuable to burn. In our concept, coal simply stops being an emitter of greenhouse gas. Instead, it becomes an engine of economic progress and job growth for communities that are too often left behind. Today, I would like to discuss briefly, a fundamentally new, environmentally positive use for coal in which carbon derived from this commodity serves as a low-cost, carbon feedstock for high-value advanced carbon products and materials. It replaces a role currently mostly served by petroleum. This field we call coal-to-products, and we have coined the phrase "carbon ore" to describe coal used in this manner.

As an overview, I would refer the Committee to the white paper that I'd shared in 2019 to then Secretary of Energy Perry from the National Coal Council entitled, "Coal in the New Carbon Age." Our advances for higher value uses for coal, borrow from developments in the United States from the earliest 20th century when coal was the basic chemical feedstock. Today, however, most carbon products are made from petroleum feedstocks. These are almost 40 times more expensive than the same carbon equivalent contained in coal. We are also now substantially behind China in pursuing this path. The IEA estimates that China annually now uses almost 400 million tons of coal a year to produce chemicals, fuels and fertilizers. Their new five-year plan calls for the construction of 370 new plants which will consume roughly a billion tons of coal by 2024. This is roughly twice the total amount of coal produced in the United States.

We embarked on our effort roughly eight years ago encouraged by new technological developments in advanced materials and manufacturing. We have worked on grants for innovative carbon research with the Department of Energy. We have had an unparalleled partnership with the national labs, especially the National Energy Technology Lab in both Pittsburgh and Albany, Oregon, as well as the Oak Ridge National Lab in Tennessee.

Today, carbon is becoming the dominant advanced material of the 21st century. Both Senators Manchin and Barrasso mentioned a number of the products involved. If we could take these new carbon products and make them for less money using coal, it could have a dramatic, positive disruption on the cost structure of many products and industries, including infrastructure. It would also dramatically improve the environmental and qualitative aspects of many products and create lots of jobs. So what carbon products and materials are we currently pursuing? As I mentioned they've been discussed but they include graphene, graphite, porous carbon, carbon fiber, building products in a variety of forms, synthetic graphites and, of course, rare earth elements.

Our recommendations are that we would ask for vastly more funding for both carbon research as well as for the national labs working with us. We would like equality under the 45Q tax credit provisions. And to implement these new technologies, we encourage ample funding and implementation of new carbon pilot plant facilities provided for in the COAL TeCC Act. Indeed, this summer we will open in Wyoming the first research pilot prototype which is pictured in my materials. As a main recommendation, however, I would encourage the development of what I call "Carbon Camps." A hundred years ago, my grandfather worked in a company store in southern West Virginia at what used to be called "Coal Camps." I know both Senators Manchin and Barrasso are very familiar with their history. The 21st century version of CAMP stands for "Carbon Advanced Materials and Product" centers. These CAMPS can repurpose older and existing mining areas across the country into new mine-mouth, higher tech, net-zero emission manufacturing hubs which NETL has estimated might create as many as 500,000 new jobs.

In conclusion, the United States possesses the world's largest and cheapest carbon reserves. It needs to capitalize on that advantage and develop its own form of a carbon valley to unlock that potential.

I thank you deeply for your time.

[The prepared statement of Mr. Atkins follows:]

TESTIMONY OF RANDALL W. ATKINS

CHAIRMAN AND CHIEF EXECUTIVE OF RAMACO COAL APPEARING BEFORE THE UNITED STATES SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES

"The New Carbon Age"

Chairman Manchin, Ranking Member Barrasso and other Senators of the Committee, it is an honor to appear before you.

I am particularly honored that the two ranking members of this Committee are from West Virginia and Wyoming, both States that I proudly call home, as well as where our companies have their operations.

Coal today is basically thought of as a cheap, controversial, environmentally challenged fuel combusted in power plants. What if we looked at the use of the commodity thru an entirely different lens and assumed that ***"coal is too valuable to burn"***. It therefore does not become an emitter of greenhouse gas.

Today, I would like to discuss a fundamentally new, environmentally positive use for carbon derived from coal. Our approach is to use the commodity as a low-cost carbon feedstock to make high-value advanced carbon products and materials that we call "**coal to products**". We have coined the phrase "**carbon ore**" to refer to coal used in this manner.

As an overview, I would first refer the Committee to the White Paper I chaired to then Secretary of Energy Perry in 2019 from the National Coal

Council entitled "Coal in the New Carbon Age".
https://www.nationalcoalcouncil.org/studies/2019/NCC-COAL-IN-A-NEW-CARBON-AGE.pdf

Our advances for the use of coal for chemical and material purposes, borrow from developments in the U.S. from the early parts of the 20th century,… before coal was supplanted by petroleum for use as a basic chemical feedstock. Today most carbon products are made from petroleum feedstocks which are almost 40 x more expensive than the same carbon equivalent from coal.

We are also substantially behind China in pursing this path. The IEA estimates that China annually now uses roughly 400 million tons of coal to produce chemicals, fuels and fertilizers. Their new 5-year plant calls for construction of 370 new coal to product plants (or one new plant a week). By 2024, they will annually consume a billion tons of coal. In comparison, the U.S. will produce this year only about 580 million tons.

We originally embarked on our effort eight years ago, encouraged by new technology developments in advanced materials and manufacturing. We have worked on grants for innovative carbon research with the Department of Energy (**DOE**). We also have had an unparalleled partnership with the National Labs, especially NETL in both Pittsburg and Albany, Oregon, as well as Oak Ridge National Lab in Tennessee.

Carbon is becoming the dominant "advanced material" of the 21st century - think carbon fiber, graphite, graphene, porous carbons and even bio-medical uses.

If we could make these carbon materials for less cost using coal, it would have a dramatic positive disruption on the cost structure of many industries, as well as improve the environmental and qualitative aspects of many products.

So what product and material areas are we currently pursuing? I refer to my appendix for a more complete description, but a partial list is:

- ***Porous activated carbons*** for fuel cells, catalytic supports and direct carbon capture,
- ***Graphene*** ranging from both high-volume applications like paint and cement additives… to also exceedingly high margin but lower volume products such as electronics and life science applications like medical diagnostics and bio-sensors,
- ***Carbon fiber*** for stronger and lighter planes, electric vehicles, missile technologies,
- ***Building products*** for new forms of commercial and residential carbon structures, basic products like rebar, fiber insulation and for rebuilding aging infrastructure
- ***Synthetic graphite*** anodes used in EV batteries, and
- ***Rare earth elements*** for electronics, magnets and strategic defense products.

We recommend vastly more funding for carbon research and implementation of the "**Coal Tecc**" provisions of the Energy Bill of 2020. We also encourage the funding of pilot facilities to implement these new carbon technologies. Indeed, this summer will open the first "iCAM" research center prototype in Wyoming pictured in the attached materials.

As a second recommendation, I would encourage the development of what I call "**Carbon Camps**". 100 years ago, my grandfather ran small company stores in southern West Virginia, at what used to be called "Coal Camps", which I know Senator Manchin is very familiar with. The 21st century version of CAMP stands for "**Carbon Advanced Materials and Product" centers**.

These CAMPs can repurpose older and existing mining areas across the country into new mine-mouth, higher tech, net zero emission manufacturing hubs. NETL has estimated this might create as many as almost 500,000 new jobs.

In conclusion, the United States possesses the world's largest and cheapest ***carbon*** reserves. It needs to capitalize on that advantage and develop its own form of a "Carbon Valley" to unlock that full potential.

I deeply thank you for your time.

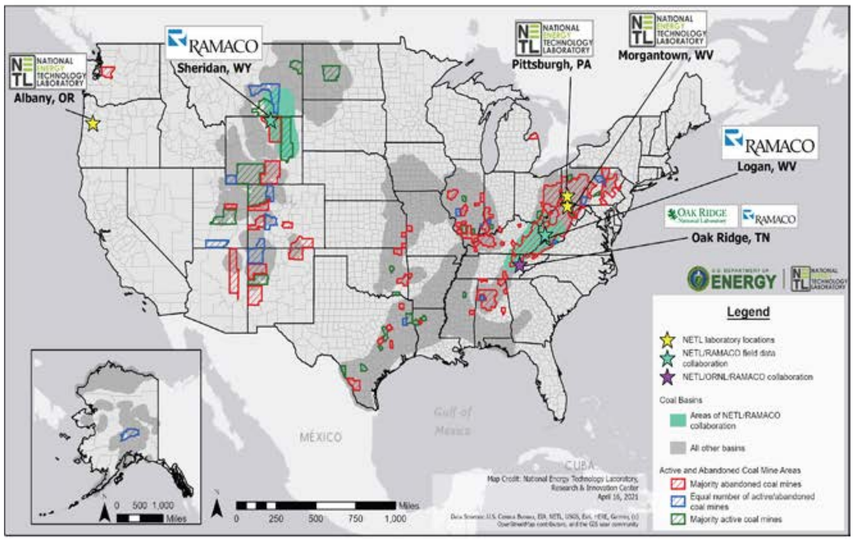
Appended Material

The Introductory Video Clip:

https://www.dropbox.com/s/tsho25mssjuj8x1/Ramaco%20Carbon%20Intro%20copy.mp4?dl=0

The new iCAM (Carbon Advanced Material Innovation Center) research and pilot facility near Sheridan, Wyoming:

Map of US Coal Basins, Ramaco Operations and Related Partner operations with National Energy Technology Laboratory (NETL) and Oak Ridge National Laboratory (ORNL):

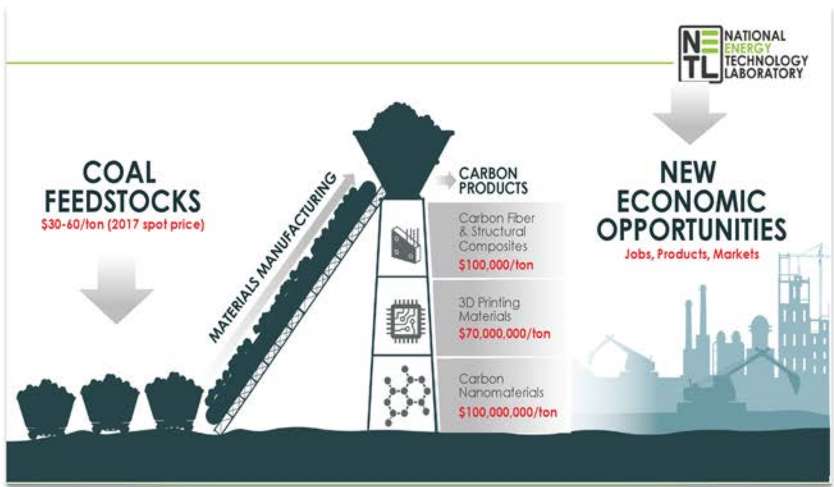


Estimate by NETL of Job Creation and Coal Usage from Development of Advanced Carbon Products and Materials:

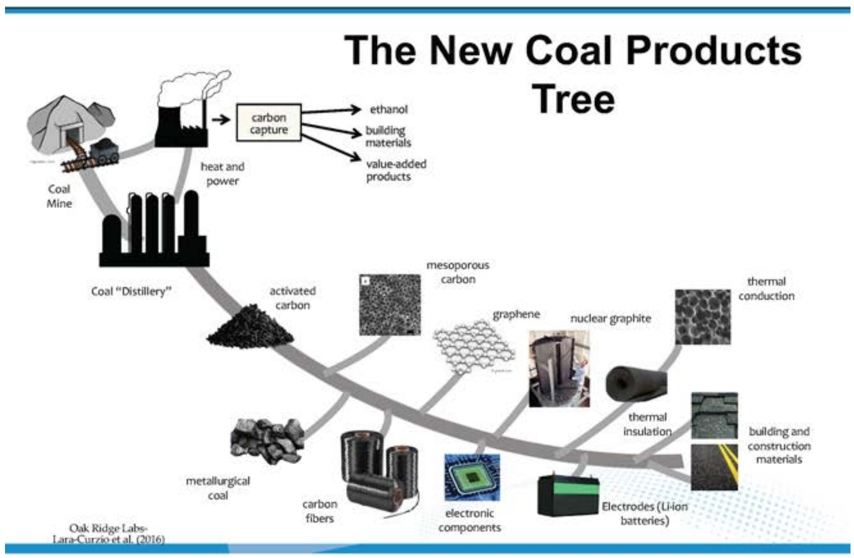
Carbon Product	Potential U.S. Coal Industry Requirements - 2050*		U.S. Product Value -2050 (Million $) *	Employment-2050 (Mfg.)*
	Coal Production (mmt)*	Coal Mining Employment*		
Activated Carbon	22	2,641	15,979	32,437
Carbon Anodes (incl. Aluminum, Li-Ion Battery Anodes)	35	4,257	31,289	63,476
Carbon Black	14.1	1,692	5,077	10,306
Graphite Electrodes/Needle Coke	12.5	1,502	41,315	83,869
Carbon Fiber (incl. CFRP, C-C composites, cement)	47.6	5,713	24,701	50,127
Carbon Nanomaterials (incl. cement)	12.1	1,457	14,125	28,300
Conductive Inks	0.001	1	264	500
Roofing Tile	2	243	7,192	14,500
Aggregate**	**100+**	**15,000+**	**TBD**	**100,000+**
Foam - Building Mat**	**100+**	**15,000+**	**TBD**	**100,000+**
Total Carbon Products	**145 to 345+**	**17,500 to 47,500+**	**139,000 +**	**280,000 to 480,000+**

* Values reported in 2050 represent a high coal penetration scenario in which carbon-based products made from coal penetrate 80 percent of the overall product market. Additionally, several products (e.g., anodes/electrodes, CF & graphene) represent high demand growth scenarios.
** Data from project estimates with technology developers for large commodity markets

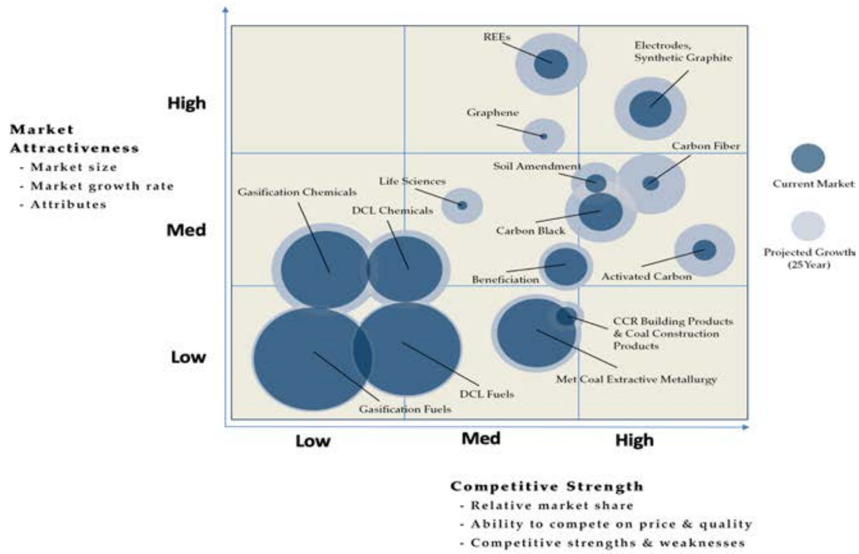
Estimate by NETL of Value Proposition from Coal Usage for Development of Advanced Carbon Products and Materials:



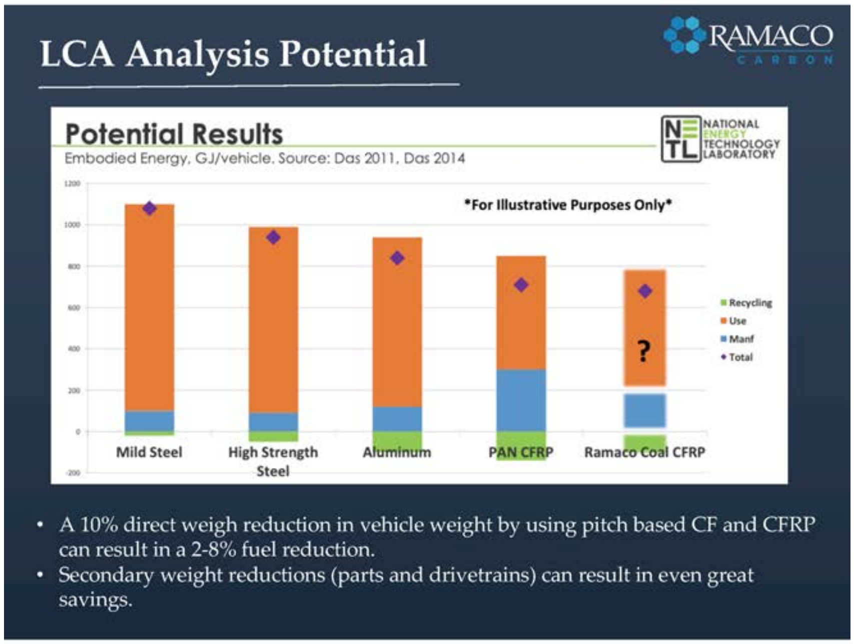
New Forms of Advanced Products & Materials from Coal Based Carbon- "The New Coal Products Tree":

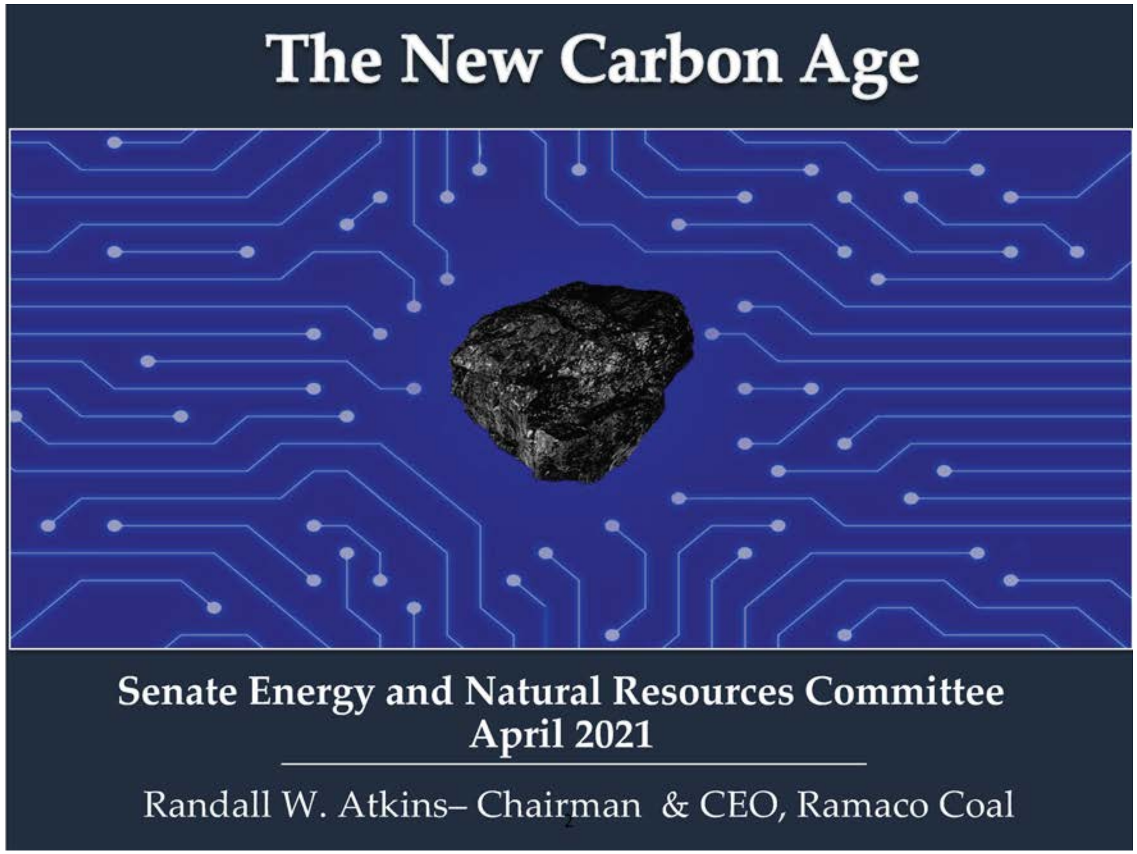


National Coal Council Estimate of Market Attractiveness and Competitive Strength of various Advanced Carbon Products & Materials:



Preliminary Life Cycle Analysis by NETL of use of Ramaco Coal to make Carbon Fibers used in Vehicles:




The New Carbon Age
Senate Energy and Natural Resources Committee
April 2021
Randall W. Atkins– Chairman & CEO, Ramaco Coal

Does Coal Have a Future?

- Since 2017, our industry has seen a dozen major bankruptcies or restructurings announced by both thermal and met coal producers in CAPP, ILB and PRB.
- Both political parties are looking for long-term solutions to this industrial, strategic and socio-economic crisis in an environmentally responsible manner.
- Since 2013, we have embarked on an unconventional, technology-focused approach to fundamentally change how we perceive and use coal.
- **Our Mantra**: "**Make coal too valuable to burn**"
- **Our Focus:** Create positive disruption by using coal as a precursor for high-value advanced carbon products and materials. This is called "**Coal to Products**" (C_2P).
- The National Coal Council's May 2019 report to the Secretary of Energy — entitled "**Coal in a New Carbon Age**" — provides a blueprint.

49


Our Goals
• To transform the coal industry into a provider of non-combustion carbon feedstock for advanced carbon products and materials.
• We no longer live in the world of Dickens. Don't think Coal. Think "Carbon Ore."
• By manufacturing high-value products and materials from coal, we could create a vastly higher economic value for it than combustion, and importantly a lower environmental footprint.
• We start by borrowing existing CTL conversion technologies from the 1970s-80s and combine them with new advancements in carbon and material research, as well as new forms of manufacturing like 3D printing.
• Thermal coal can have a vastly more valuable end use than power. Even metallurgical coal can have a higher value than coking for steel. As the price of coal rises, it could create a virtuous cycle… currently stranded, higher-cost coals become economic to mine.
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CARBON
4


We knew even 50 years ago there was a different path
RAMACO
CARBON
FROM THE COAL MINES OF WEST VIRGINIA
Bituminous Coal
Fossil Fern Leaf
Cannel Coal
PRODUCTS MADE FROM COAL
Peat
Nylon
Dye & Ink Colors
Synthetic Rubber
Aspirin & Saccharin
Coke
A souvenir made for then-Senator John F. Kennedy by 6th graders in Huntington, West Virginia *Credit: JFK Presidential Library & Museum*
5

Our Socio-Economic Plan: Carbon CAMPs

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- **Create an ecosystem of net-zero emission manufacturing hubs** around the country, producing carbon products from coal.
- These are called **Carbon CAMP centers**, for "Carbon Advanced Materials, Manufacturing and Production.
- Locate CAMP centers in coal-producing areas where mine-mouth logistical advantages and access to smart, skilled coal mining talent can be accentuated.
- We "repurpose" older mining communities into advanced manufacturing hubs.
- Focus on the manufacture of environmental carbon products and materials with high value margins, *and* which require the use of coal as the basic carbon feedstock.
- **Build an innovative, higher tech future for the coal industry** independent of power trends and environmental concerns.

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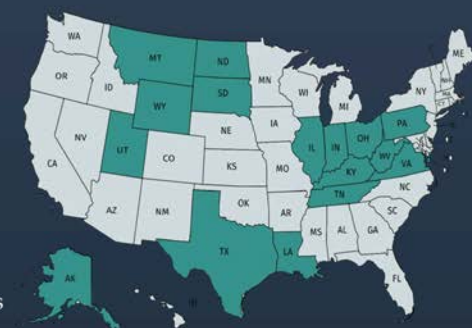
CAMP Centers in Coal States

- With Federal and State support, construction could start almost immediately.
- The Federal Government can fund a public/private pilot center and pre-commercial facilities per Coal Tecc legislation already passed.
- We plan to invest in center in coal states with our existing production like West Virginia, Wyoming, Pennsylvania, Virginia, Kentucky, and more.
- Creating CAMP centers near mines creates synergies with huge logistical cost advantages.
- Even non-coal coastal states have significant economic and political interests in advanced carbon materials and life sciences.



New Job Creation and Production Potential

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Carbon Product	Potential U.S. Coal Industry Requirements - 2050*		U.S. Product Value -2050 (Million $) *	Employment-2050 (Mfg.)*
	Coal Production (mmt)*	Coal Mining Employment*		
Activated Carbon	22	2,641	15,979	32,437
Carbon Anodes (incl. Aluminum, Li-Ion Battery Anodes)	35	4,257	31,289	63,476
Carbon Black	14.1	1,692	5,077	10,306
Graphite Electrodes/Needle Coke	12.5	1,502	41,315	83,869
Carbon Fiber (incl. CFRP, C-C composites, cement)	47.6	5,713	24,701	50,127
Carbon Nanomaterials (incl. cement)	12.1	1,457	14,125	28,300
Conductive Inks	0.001	1	264	500
Roofing Tile	2	243	7,192	14,500
Aggregate**	**100+**	**15,000+**	**TBD**	**100,000+**
Foam - Building Mat**	**100+**	**15,000+**	**TBD**	**100,000+**
Total Carbon Products	**145 to 345+**	**17,500 to 47,500+**	**139,000 +**	**280,000 to 480,000+**

* Values reported in 2050 represent a high coal penetration scenario in which carbon-based products made from coal penetrate 80 percent of the overall product market. Additionally, several products (e.g., anodes/electrodes, CF & graphene) represent high demand growth scenarios.
** Data from project estimates with technology developers for large commodity markets

Carbon Derived from Coal

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- Carbon is becoming the dominant "**advanced material**" of the 21st Century — think carbon fiber, graphene, graphite and carbon resins.
- We're entering a **Carbon Age**.
- The United States could lead a wave of innovation by making carbon products and materials from **coal instead of petroleum**. This would generate significant manufacturing opportunities for mining communities.
- Cheaper materials made from coal could enhance or replace both key metals (i.e. steel, aluminum), as well as basic building products (i.e. asphalt, rebar, roof shingles). Carbon also has applications in chemicals, resins and even life sciences.
- These are fast-growing, game changing uses requiring huge volumes of coal.
- This could enable disruption in manufacturing by lowering cost on a massive scale. Just a few new large scale uses could create a demand inflection point for the entire US coal industry.

Displacement Potential of Carbon from Coal

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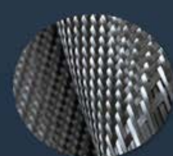
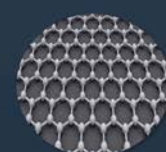
- Coal's potential is to make advanced carbon materials **that are stronger, lighter, and most importantly cheaper.**
- The key to coal's advantage is cost. It is far cheaper than petroleum, the typical precursor for advanced carbon materials .
- Materials that can be made from coal instead of petroleum include:



Carbon Fiber

Carbon fiber is 50% the weight of aluminum but 4X as strong. It is 25% the weight of steel but 2X as strong.



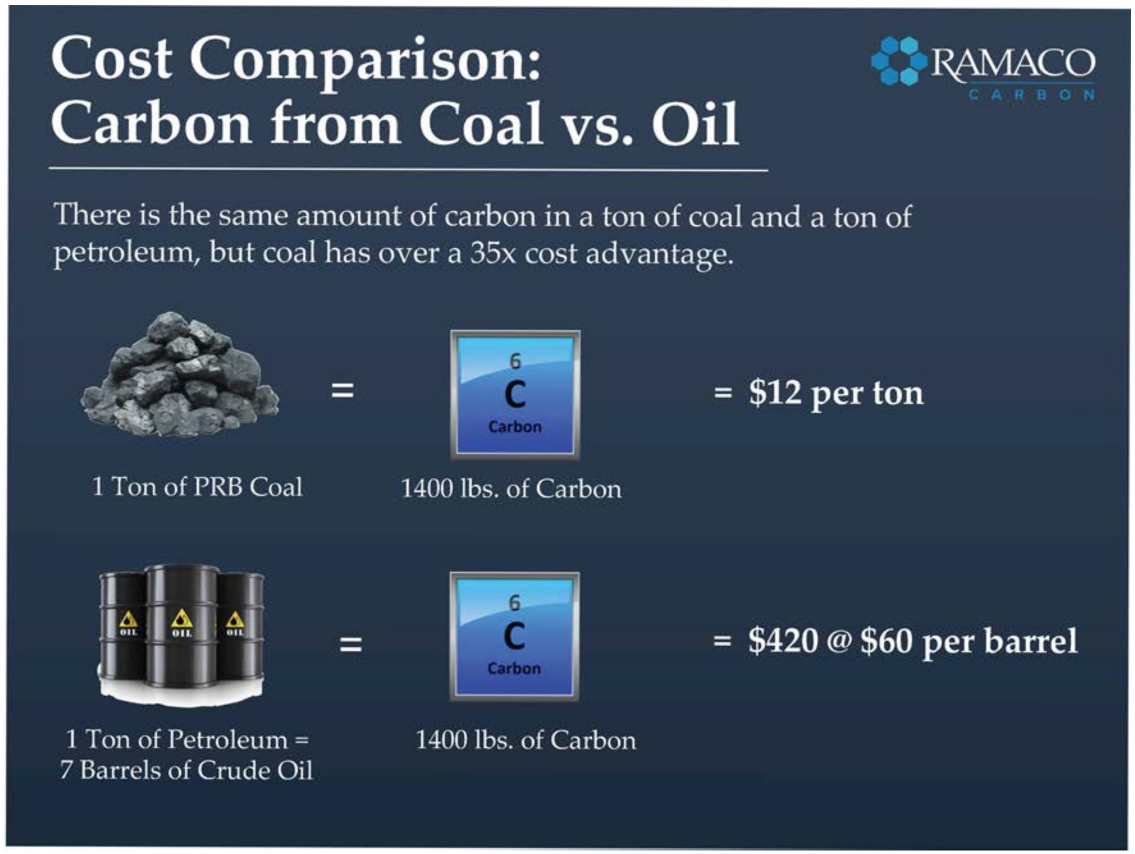
Graphene

Used to conduct heat and electricity, this material is thinner than paper and can be harder than a diamond.

Graphite

Used to make brake linings, lubricants, and molds in foundries, as well as in the production of steel.

10


Cost Comparison:
Carbon from Coal vs. Oil
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There is the same amount of carbon in a ton of coal and a ton of petroleum, but coal has over a 35x cost advantage.
=
6
C
Carbon
= $12 per ton
1 Ton of PRB Coal
1400 lbs. of Carbon
OIL
=
6
C
Carbon
= $420 @ $60 per barrel
1 Ton of Petroleum =
7 Barrels of Crude Oil
1400 lbs. of Carbon


Where are we headed?
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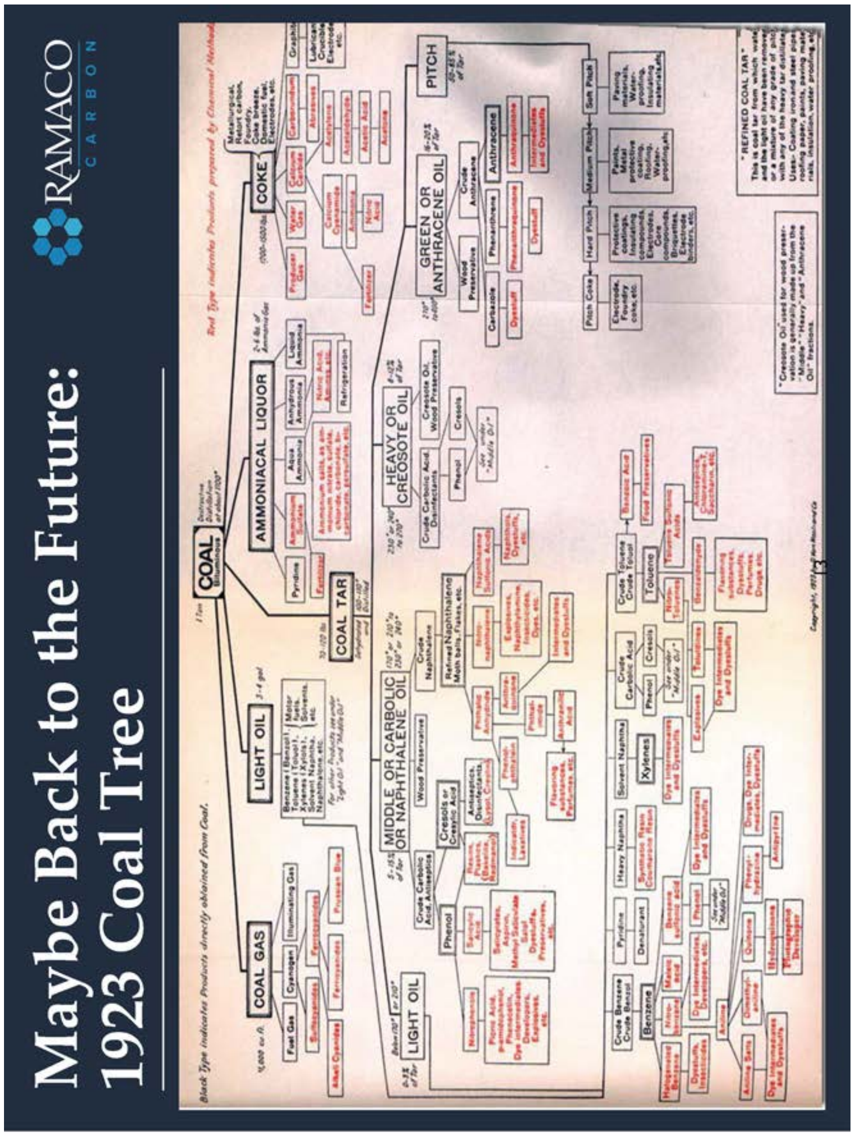
12


Maybe Back to the Future:
1923 Coal Tree
RAMACO
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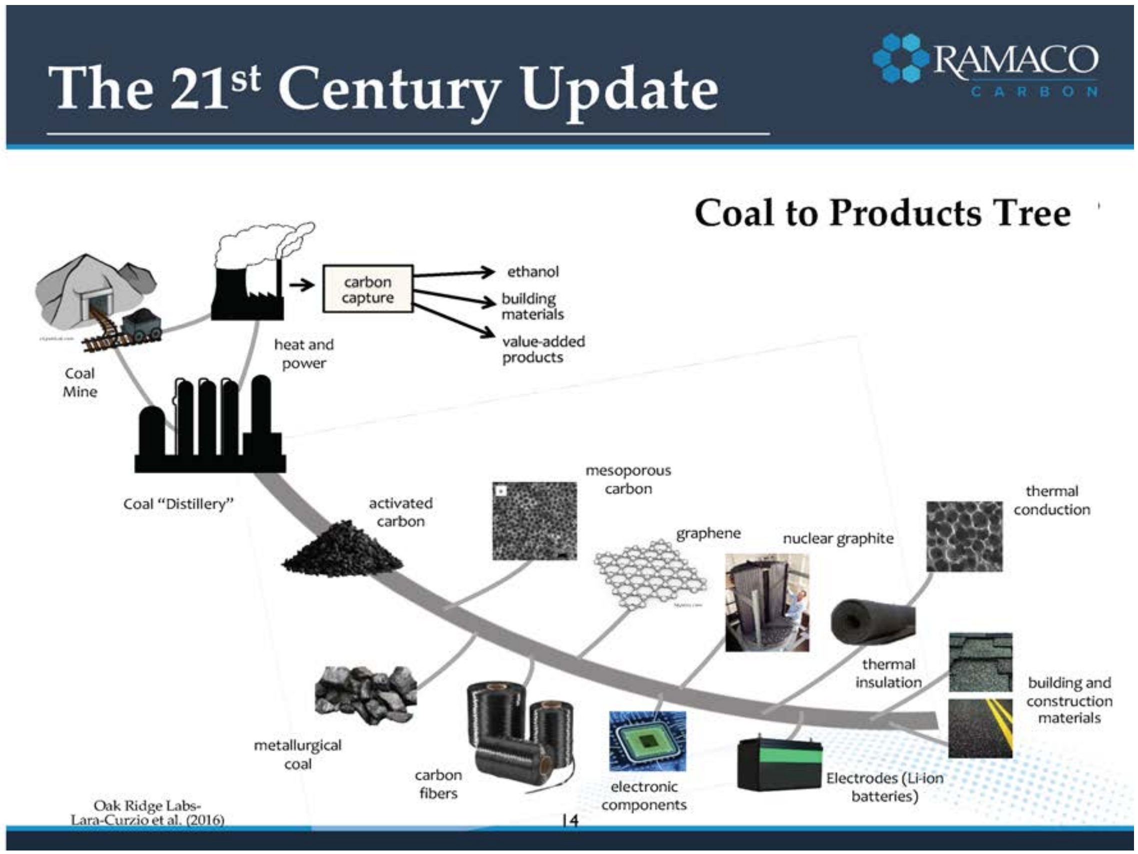
COAL
COAL GAS
LIGHT OIL
COAL TAR
AMMONIACAL LIQUOR
COKE
PITCH
MIDDLE OR CARBOLIC OR NAPHTHALENE OIL
HEAVY OR CREOSOTE OIL
GREEN OR ANTHRACENE OIL



The 21st Century Update
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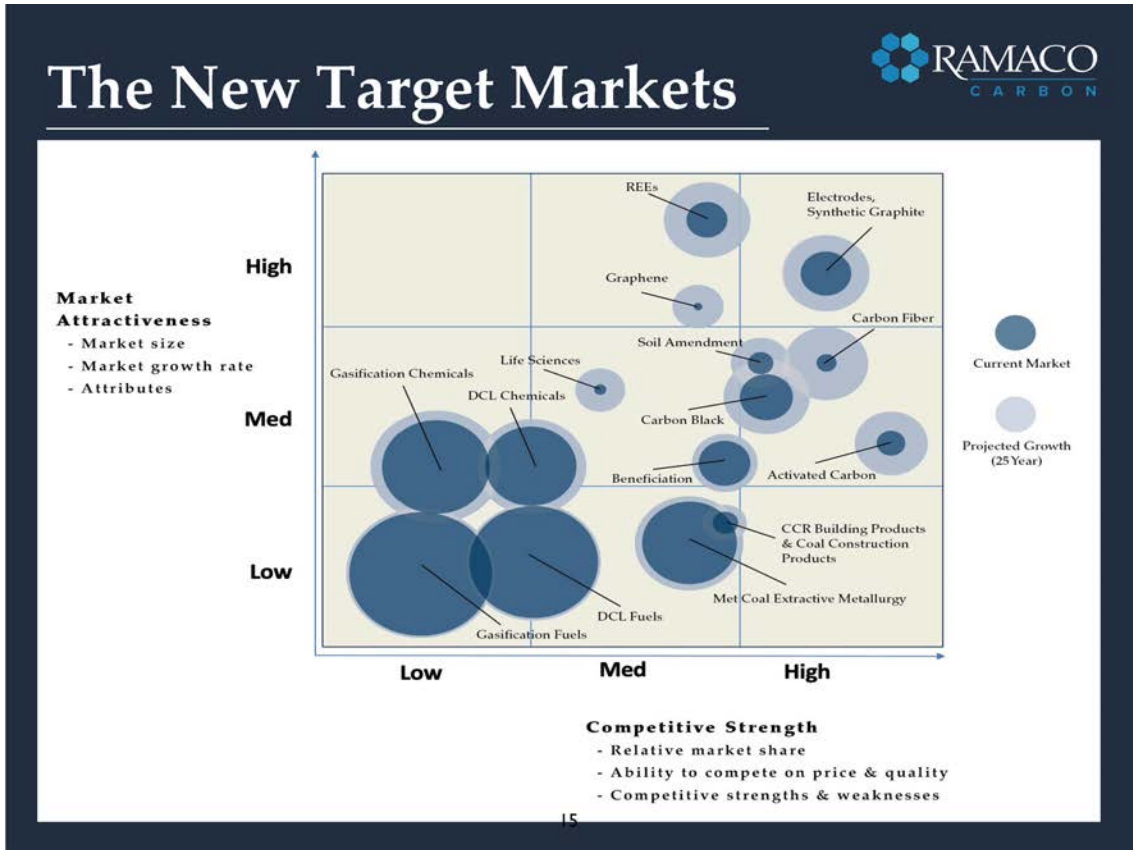
Coal to Products Tree
Coal Mine
heat and power
carbon capture
ethanol
building materials
value-added products
Coal "Distillery"
activated carbon
mesoporous carbon
graphene
nuclear graphite
thermal conduction
thermal insulation
building and construction materials
metallurgical coal
carbon fibers
electronic components
Electrodes (Li-ion batteries)
Oak Ridge Labs-
Lara-Curzio et al. (2016)
14



The New Target Markets
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Market Attractiveness
- Market size
- Market growth rate
- Attributes
High
Med
Low
REEs
Electrodes, Synthetic Graphite
Graphene
Carbon Fiber
Soil Amendment
Life Sciences
Gasification Chemicals
DCL Chemicals
Carbon Black
Beneficiation
Activated Carbon
CCR Building Products & Coal Construction Products
Met Coal Extractive Metallurgy
DCL Fuels
Gasification Fuels
Current Market
Projected Growth (25 Year)
Low
Med
High
Competitive Strength
- Relative market share
- Ability to compete on price & quality
- Competitive strengths & weaknesses
15

Coal to Products Value Proposition

Who We Are

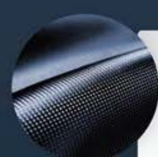
Founded in 2011, **Ramaco Coal** is a coal-based conglomerate with operations in five states. It consists of two main operating companies:

RAMACO RESOURCES

A publicly traded met coal producer (NASDAQ: METC) with low cost, high quality production in West Virginia, Virginia and Pennsylvania.

Headquartered in Lexington, Kentucky.

www.ramacoresources.com



RAMACO CARBON

The first vertically integrated resource, research and manufacturing coal technology platform, focused on creating "Coal to Products".

Headquartered in Sheridan, Wyoming.

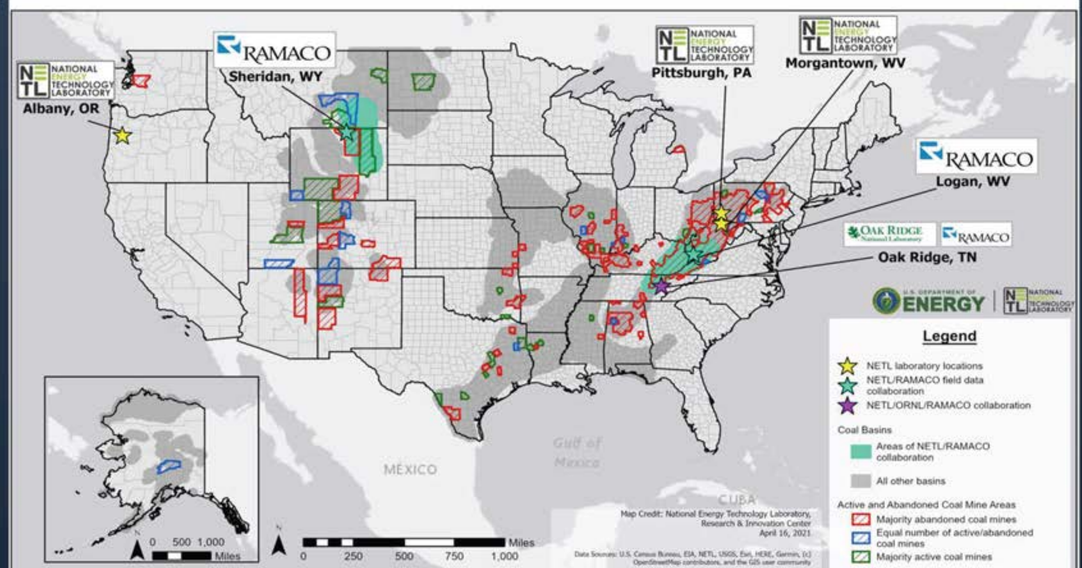
www.ramacocarbon.com

Where We Are

RAMACO CARBON

We operate in two of the major coal basins of the United States: the Central Appalachia Basin (WV, VA, PN) and the Powder River Basin (WY).

With our partners at the National Labs we spread the field even more.



What We Are: A Carbon Tech Company

RAMACO CARBON

COAL RESERVES

Ramaco Carbon owns the Brook Mine in Wyoming, a 1.1 billion ton privately owned coal resource.

Ramaco Coal also owns 250+ million tons of metallurgical coal reserves mostly in West Virginia.

RESEARCH PARK

The iCAM research-pilot plant park in Wyoming will be completed this summer. An additional lab is in the works in West Virginia.

These research facilities will incubate carbon research to commercialize coal-based carbon products, from bench through commercial stage.

INDUSTRIAL PARK

The iPark is a contiguous 100+ acre "coal to products" mine-mouth manufacturing park, next to the Brook Mine.

Companies will use coal from the Brook Mine to manufacture advanced carbon products and materials.

Unique Partners

- We are privileged to work with top U.S. National Labs, research institutes, strategic groups and universities, who form our core research and development network.
- We are also do critical development with both the NETL and Oak Ridge National Laboratory through joint research partnerships on developing a variety of coal process and carbon product and material technologies.
- Over 50 scientists have come together for the past two summers for the **Ramaco Research Rodeo (the "R3")**, a coal-to-products research conference held in Sheridan, Wyoming.
- We are now involved in **five grants from the Department of Energy** to explore novel uses of coal to make carbon products.

Partners include:

- National Energy Technology Laboratory
- Oak Ridge National Laboratory
- MIT- The Grossman Materials Group
- Fluor Corporation
- TerraPower, LLC
- HTI-Axens
- West Virginia Univ.
- Univ. of Illinois-Chicago
- Western Research Institute
- Southern Research Institute

Our Product Focus

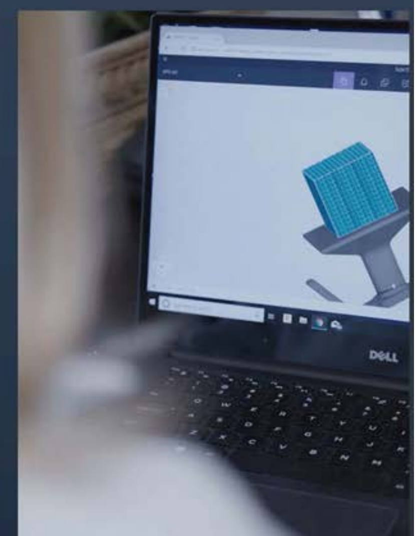
RAMACO CARBON

We focus on six broad carbon based uses :

1) **Carbon Fiber ("CF")**
2) **Graphene**
3) **Building Products**
4) **Advanced Porous Carbons**
5) **Bio-Medical Technology**
6) **Rare Earth Elements ("REE")**

We seek uses that marry advanced materials and advanced manufacturing technologies.

These uses have both a high margin value proposition and can require large coal volumes.



Coal to Cars?

- We are in our 2nd year of a DOE grant with many national partners nicknamed **"Coal to Cars."** The focus is using coal to make low cost carbon fiber for vehicles.
- Carbon fiber is used in less than 10% of cars currently manufactured, despite benefits in gas mileage, strength, and more.
- CF is 4x lighter than steel and 2x as strong. It is 2x lighter than aluminum and 4x as strong.
- The barrier is its high cost. CF now made from petroleum is 8x more expensive than steel. We are working to drive the price of the coal-based precursor beneath a "tipping point." CF then becomes affordable alternative to steel.
- CF Precursor costs could drop from \$25-40 p/lb. to below \$5.
- CF cars then move from niche markets — such as F1 racing — to mass market. Lighter vehicles equal less gas consumption and huge environmental benefits.

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Evolution of Coal to Carbon Fiber Cars
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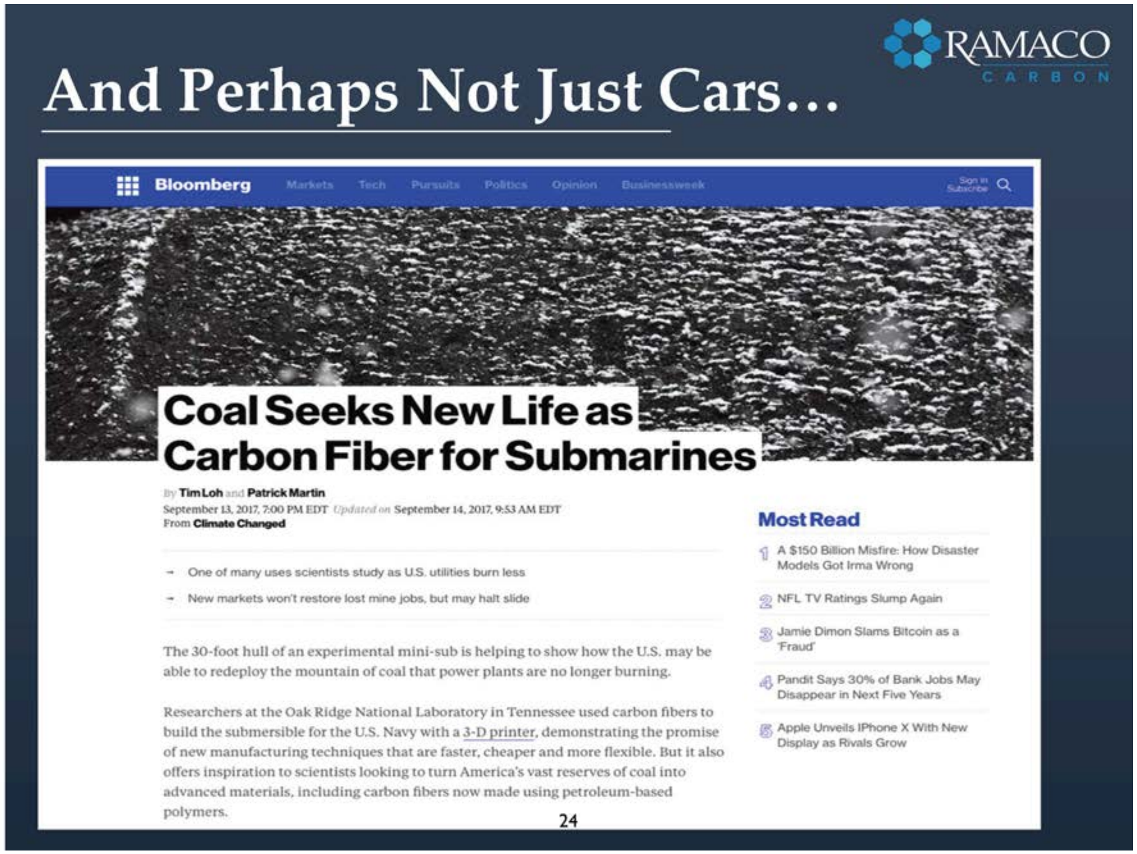
CARBON
FIRST
NOW
NEXT
High End & Niche
Low Volume Production of Affordable Car
Mass Market Appeal
High End Low Volume Hand Layup
Low Volume Production
High Volume Production
?
23


And Perhaps Not Just Cars…
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Bloomberg
Markets Tech Pursuits Politics Opinion Businessweek
Coal Seeks New Life as Carbon Fiber for Submarines
By Tim Loh and Patrick Martin
September 13, 2017, 7:00 PM EDT Updated on September 14, 2017, 9:53 AM EDT
From Climate Changed
→ One of many uses scientists study as U.S. utilities burn less
→ New markets won't restore lost mine jobs, but may halt slide
The 30-foot hull of an experimental mini-sub is helping to show how the U.S. may be able to redeploy the mountain of coal that power plants are no longer burning.
Researchers at the Oak Ridge National Laboratory in Tennessee used carbon fibers to build the submersible for the U.S. Navy with a 3-D printer, demonstrating the promise of new manufacturing techniques that are faster, cheaper and more flexible. But it also offers inspiration to scientists looking to turn America's vast reserves of coal into advanced materials, including carbon fibers now made using petroleum-based polymers.
Most Read
1 A $150 Billion Misfire: How Disaster Models Got Irma Wrong
2 NFL TV Ratings Slump Again
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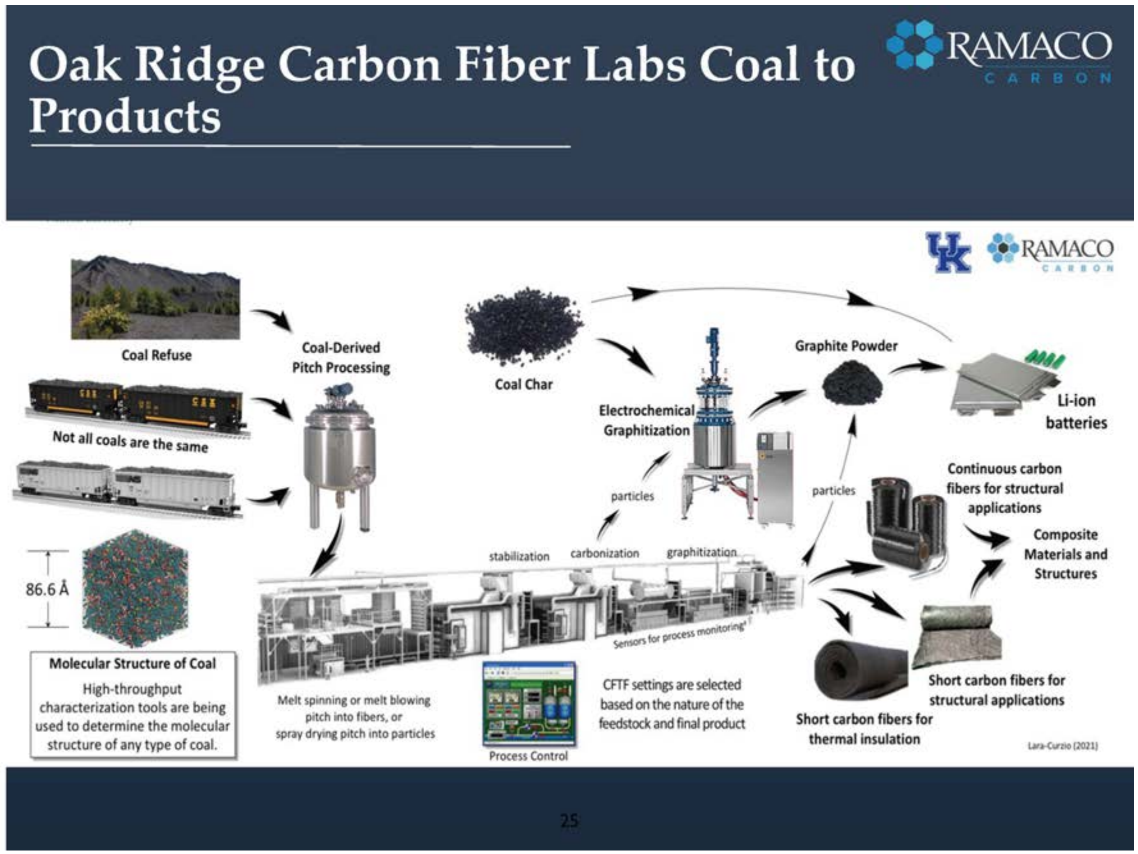
4 Pandit Says 30% of Bank Jobs May Disappear in Next Five Years
5 Apple Unveils IPhone X With New Display as Rivals Grow
24


Oak Ridge Carbon Fiber Labs Coal to Products
RAMACO CARBON
Coal Refuse
Not all coals are the same
86.6 Å
Molecular Structure of Coal
High-throughput characterization tools are being used to determine the molecular structure of any type of coal.
Coal-Derived Pitch Processing
Melt spinning or melt blowing pitch into fibers, or spray drying pitch into particles
Process Control
Coal Char
Electrochemical Graphitization
particles
stabilization
carbonization
graphitization
Sensors for process monitoring
CFTF settings are selected based on the nature of the feedstock and final product
Graphite Powder
Li-ion batteries
Continuous carbon fibers for structural applications
Composite Materials and Structures
Short carbon fibers for structural applications
Short carbon fibers for thermal insulation
Lara-Curzio (2021)
25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Carbon Fiber Value Proposition
Raw Coal
$0.03/kg
Metallurgical Coal
$0.15/kg
Coke
$0.25/kg
タール
Coal Tar
$0.40/kg
Coal Tar Pitch
$0.70/kg
Mesophase Coal Tar Pitch Precursor
$3.30/kg
Pitch Carbon Fiber
$11.00/kg
A huge value creation from $.03/kg for raw coal to over
$11.00/kg for Pitch based carbon fiber
26
OAK RIDGE
National Laboratory

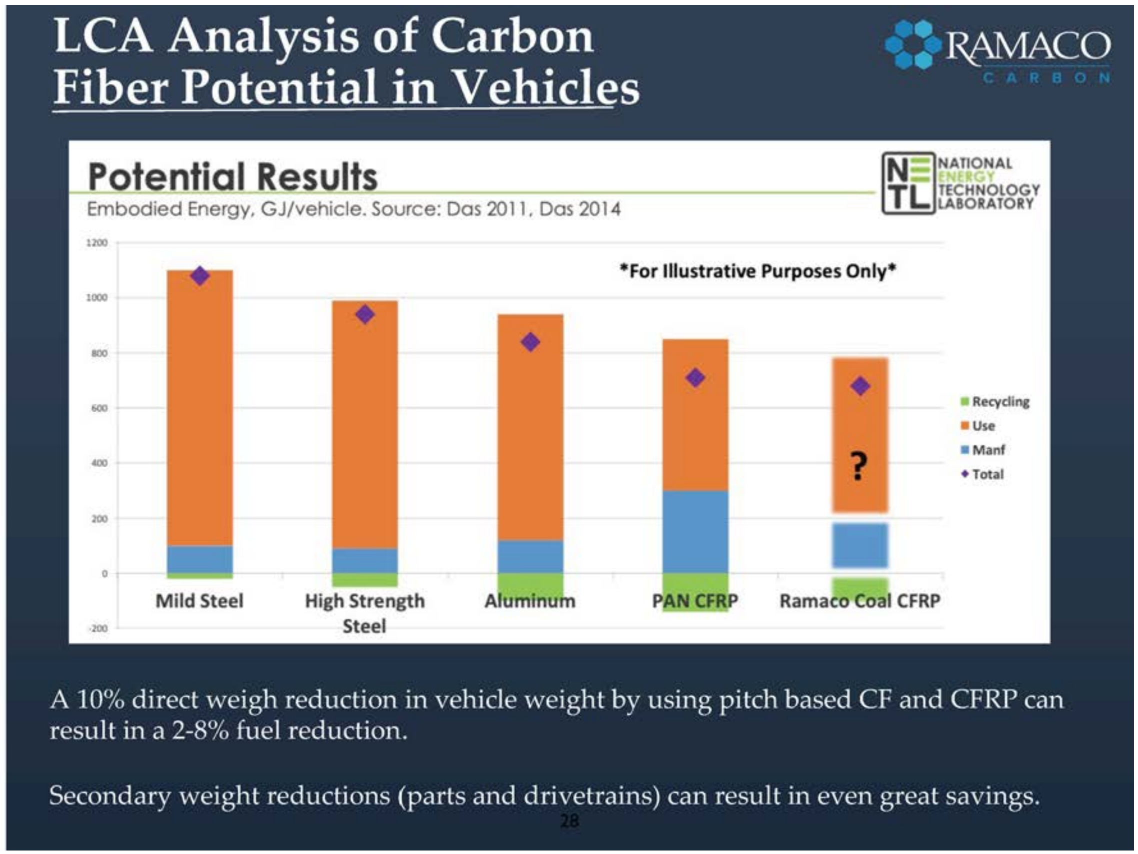
LCA Analysis of Coal-Based Products

RAMACO CARBON

- In partnership with NETL, we are involved in a ground-breaking environmental "Life Cycle Analysis" (LCA) to assess the environmental impacts of various coal-based advanced products and materials from extraction to disposal.
- The first LCA analysis involves the use of coal-based CF and CFRP to make lighter weight vehicles.
- Coal-based (pitch) CF precursors are 85% carbon. Petroleum-based precursors are only 50% carbon. Less processing energy is therefore needed to create CF. Coal-based CF may also involve novel production techniques to lower carbon footprint.
- The same environmental advantages that coal based advanced material brings to CF can also be applied across other products and materials.

LCA Goal and Scope

- **Goal: To assess the life-cycle environmental impacts of using coal-derived CFRP in light vehicle structural components.**
- **Scope: The following stages will be considered**
  - Production of raw materials
  - Production of vehicle
  - Fuel use during operation
  - Recycling
- **Impacts: TRACI impact categories (Acidification, Eutrophication, Greenhouse gases, Ozone depletion, Smog formation, Water use)**


LCA Analysis of Carbon Fiber Potential in Vehicles
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Potential Results
Embodied Energy, GJ/vehicle. Source: Das 2011, Das 2014
NATIONAL ENERGY TECHNOLOGY LABORATORY
For Illustrative Purposes Only
1200
1000
800
600
400
200
0
-200
Mild Steel
High Strength Steel
Aluminum
PAN CFRP
Ramaco Coal CFRP
?
Recycling
Use
Manf
Total
A 10% direct weigh reduction in vehicle weight by using pitch based CF and CFRP can result in a 2-8% fuel reduction.
Secondary weight reductions (parts and drivetrains) can result in even great savings.
28

Coal to Rare Earth Elements

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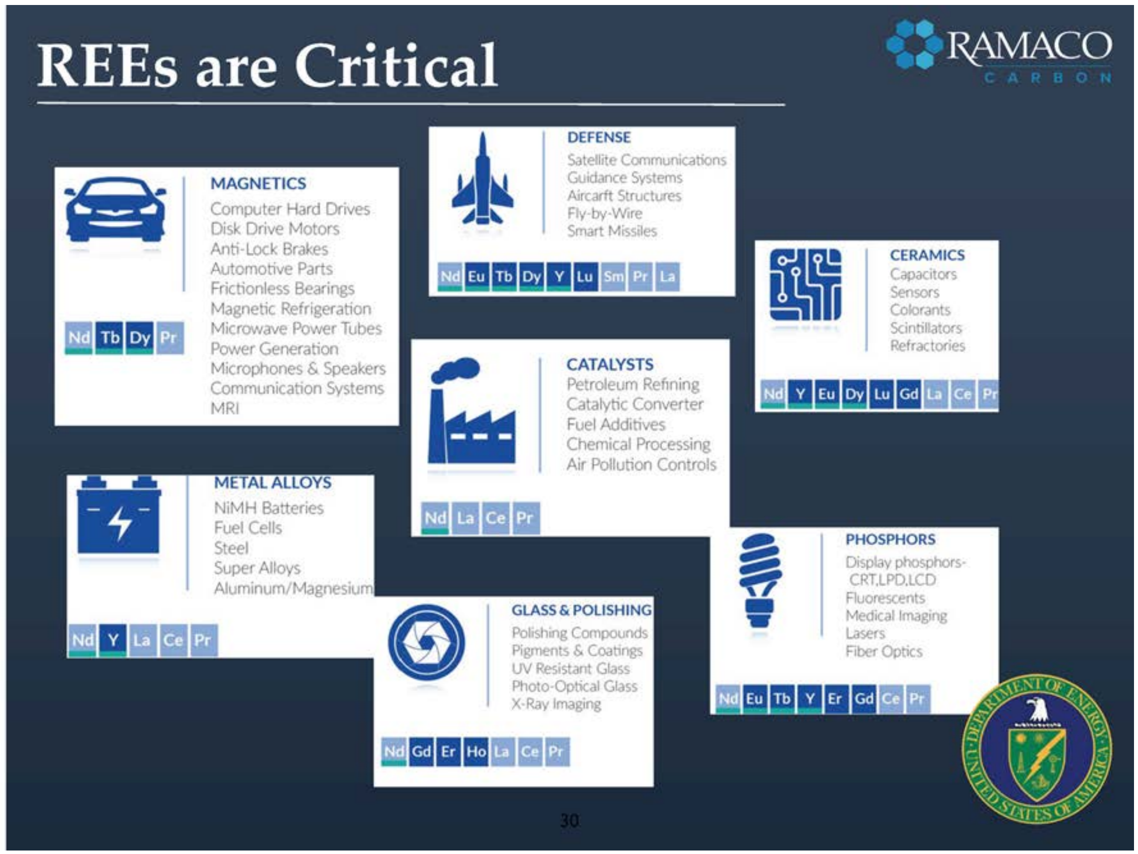
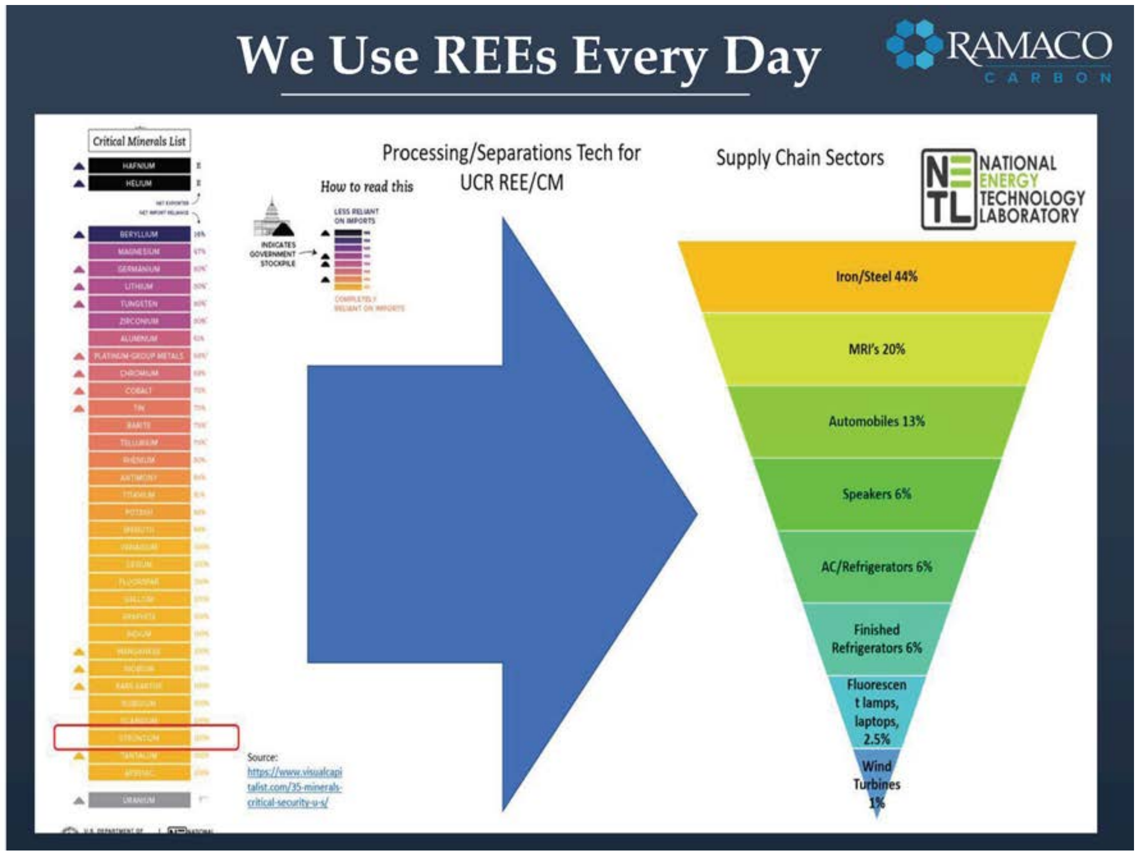
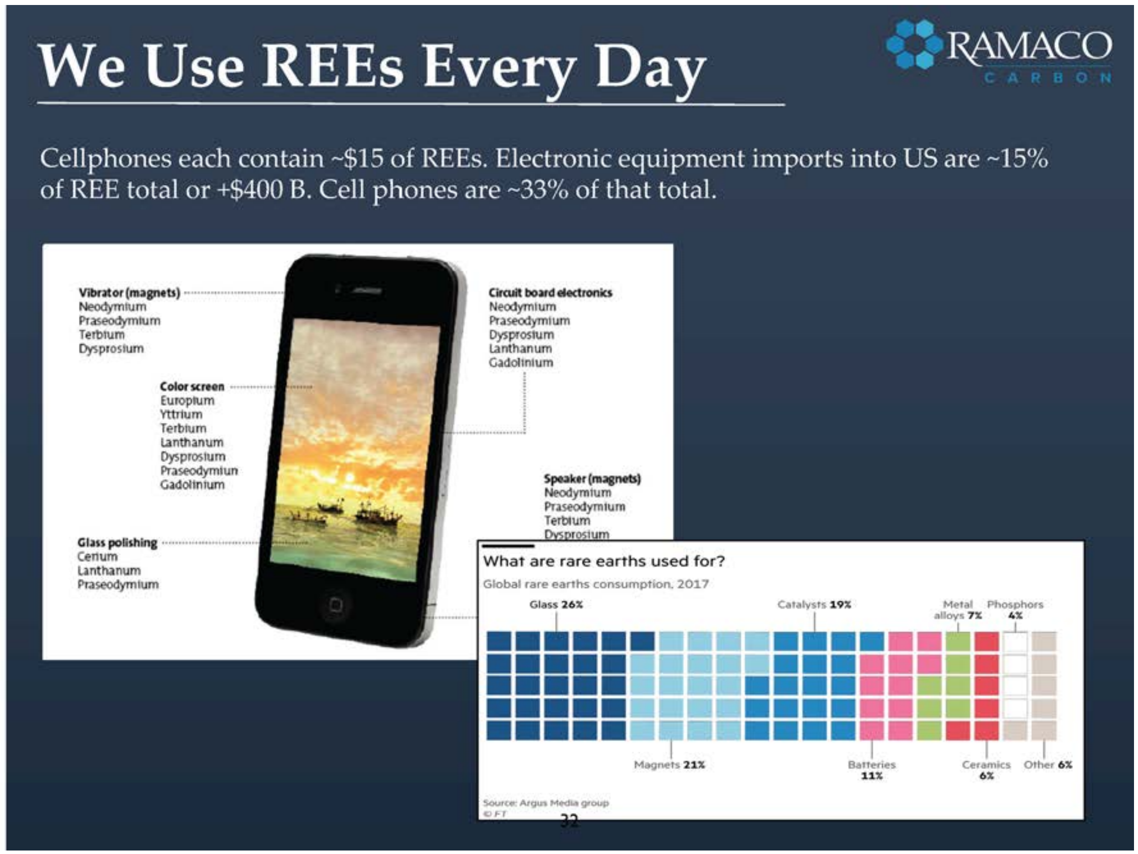
- Rare Earth Elements (REE) are chemical elements/metals found in low concentrations throughout the Earth's crust, making them hard to recover.
- They are found in coal, coal ash, clay, shale, and in over- and under-burdens in quantities measured in parts per million.

- **95% of all REE are imported from China.**
- The global market approaches $10 B per year with the U.S. consuming +10% by volume. Most REEs are imported into U.S. as finished goods, not raw.
- **The level of these imported goods will approach +$1.5 T in 2020.**


REEs are Critical
RAMACO
CARBON
MAGNETICS
Computer Hard Drives
Disk Drive Motors
Anti-Lock Brakes
Automotive Parts
Frictionless Bearings
Magnetic Refrigeration
Microwave Power Tubes
Power Generation
Microphones & Speakers
Communication Systems
MRI
Nd Tb Dy Pr
DEFENSE
Satellite Communications
Guidance Systems
Aircarft Structures
Fly-by-Wire
Smart Missiles
Nd Eu Tb Dy Y Lu Sm Pr La
CERAMICS
Capacitors
Sensors
Colorants
Scintillators
Refractories
Nd Y Eu Dy Lu Gd La Ce Pr
CATALYSTS
Petroleum Refining
Catalytic Converter
Fuel Additives
Chemical Processing
Air Pollution Controls
Nd La Ce Pr
METAL ALLOYS
NiMH Batteries
Fuel Cells
Steel
Super Alloys
Aluminum/Magnesium
Nd Y La Ce Pr
GLASS & POLISHING
Polishing Compounds
Pigments & Coatings
UV Resistant Glass
Photo-Optical Glass
X-Ray Imaging
Nd Gd Er Ho La Ce Pr
PHOSPHORS
Display phosphors-
CRT,LPD,LCD
Fluorescents
Medical Imaging
Lasers
Fiber Optics
Nd Eu Tb Y Er Gd Ce Pr
DEPARTMENT OF ENERGY UNITED STATES OF AMERICA
30



We Use REEs Every Day
RAMACO
CARBON
Critical Minerals List
HAFNIUM
HELIUM
BERYLLIUM
MAGNESIUM
GERMANIUM
LITHIUM
TUNGSTEN
ZIRCONIUM
ALUMINUM
PLATINUM GROUP METALS
CHROMIUM
COBALT
TIN
URANIUM
How to read this
INDICATES GOVERNMENT STOCKPILE
LESS RELIANT ON IMPORTS
COMPLETELY RELIANT ON IMPORTS
Processing/Separations Tech for
UCR REE/CM
Supply Chain Sectors
NATIONAL
ENERGY
TECHNOLOGY
LABORATORY
Iron/Steel 44%
MRI's 20%
Automobiles 13%
Speakers 6%
AC/Refrigerators 6%
Finished Refrigerators 6%
Fluorescen t lamps, laptops, 2.5%
Wind Turbines 1%
Source:
https://www.visualcapitalist.com/35-minerals-critical-security-u-s/


We Use REEs Every Day
RAMACO
CARBON
Cellphones each contain ~$15 of REEs. Electronic equipment imports into US are ~15% of REE total or +$400 B. Cell phones are ~33% of that total.
Vibrator (magnets)
Neodymium
Praseodymium
Terbium
Dysprosium
Color screen
Europium
Yttrium
Terbium
Lanthanum
Dysprosium
Praseodymiun
Gadolinium
Glass polishing
Cerium
Lanthanum
Praseodymium
Circuit board electronics
Neodymium
Praseodymium
Dysprosium
Lanthanum
Gadolinium
Speaker (magnets)
Neodymium
Praseodymium
Terbium
Dysprosium
What are rare earths used for?
Global rare earths consumption, 2017
Glass 26%
Catalysts 19%
Metal alloys 7%
Phosphors 4%
Magnets 21%
Batteries 11%
Ceramics 6%
Other 6%
Source: Argus Media group
© FT
32

The Challenge of REEs

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The U.S. needs to **regain an ability to control the supply of REEs** which are critical to both our National Security and so many industries.

The U.S. Department of Energy, working with the National Energy Technology Laboratory, is attacking the problem by:

- Understanding how (and where) REEs occur in coal and by-products
- Developing with industry, new technologies for prospecting and producing REEs.
- Promoting new transformational separation technologies to produce both more ore quality and greater amounts of REEs from coal.

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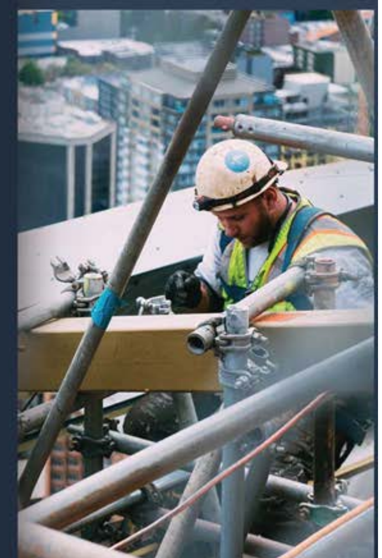
Coal to Building Products

Another disruptive large-scale use for coal is building products, which has the potential to require even greater coal volumes than carbon fiber.

The range of *current* product uses is practically endless, and include:

- **Rebar —** CF rebar can provide flexibility to concrete structures, does not expand with temperature changes, is lighter than steel rebar, and does not rust.
- **Roofing —** Coal-based pitch asphalt roof shingles could become a regular feature of buildings.
- **Repair Aging Infrastructure** (think bridge renovations): Can be molded around existing older infrastructure to provide structural strength, increasing lifespan by 2-3x at a fraction of the weight.



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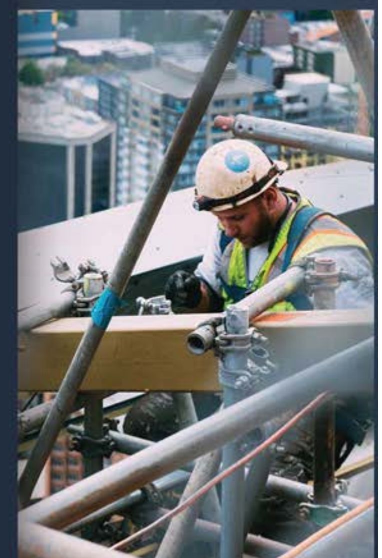
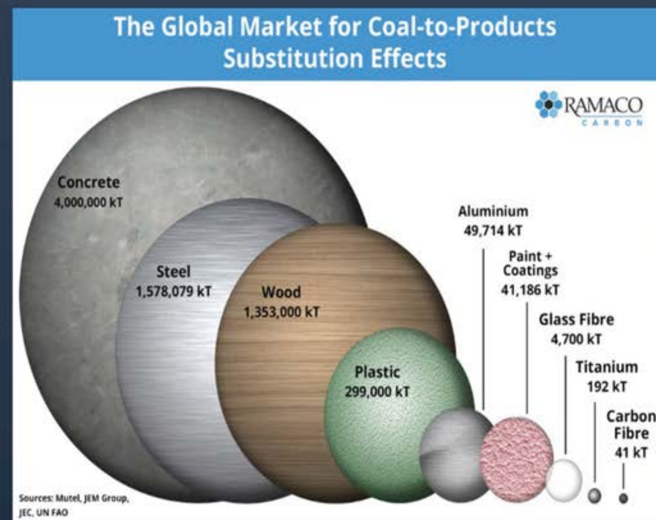
Coal to Building Products

- MIT architect Mark Goulthrope, projects by 2050 the global population will increase to ~11 billion people overall. In only 30 years, the world will double the aggregate mass of all building structures currently on the planet.
- **There is not enough concrete, wood and steel to build this reality**.
- Working with our partners at the National Labs, we proposed creating "net negative" CO_2 buildings comprised of carbon building materials ("CBM").
- The goal is to have a complete "Carbon Building" by 2030.
- These buildings can be built quicker, lighter, stronger, more easily and less expensively than today's conventional structures.



Coal Building Materials: The "Substitution" Impact

- Over time CBM can replace a large percentage of current Basic Building Materials ("BBM") or be integrated with BBM to create new products.
- If we assume CBM could substitute for ~10% of BBM over time, <u>this could require the equivalence of 2.8 B tons of annual coal consumption.</u>
- CBM can also be combined with BBM as a transition to larger use of CBM.



Potential Global Substitution Markets for Coal-Derived Building Products (2016 Quantities)

Construction & Infrastructure Materials

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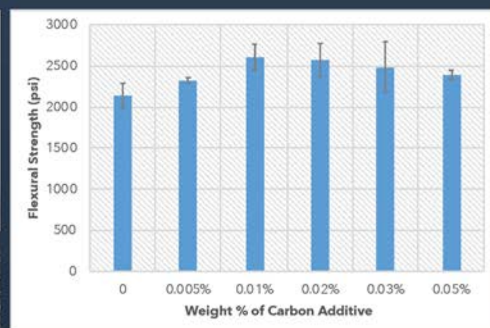

Coal-derived graphene nanoflake in cement/concrete formulations:

- Increases compressive and flexural strength by 15-35%
- Reduces porosity by 35% and permeability by 100%,
- Improves corrosion resistance

Coal Materials: Engineered Graphene Nanoflake


Coal Foams: Early Starts on CBM
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38

Biosensing & Medical Diagnostics

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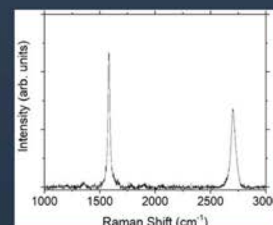
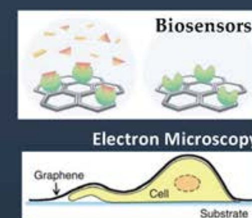
Optical Tags

Graphene quantum dots (luminescent)

Used as optical tags for imaging applications

Biosensors & Microscopy





3-6 layer, low defect, graphene from coal CVD

Used for biosensor & electron microscopy applications

Coal Materials: Graphene Quantum Dots, Graphene Films, Carbon Nanosheets

Cell image: Nat. Commun. vol. **6**, article No: 7384 (2015)

Carbon Computer Memory

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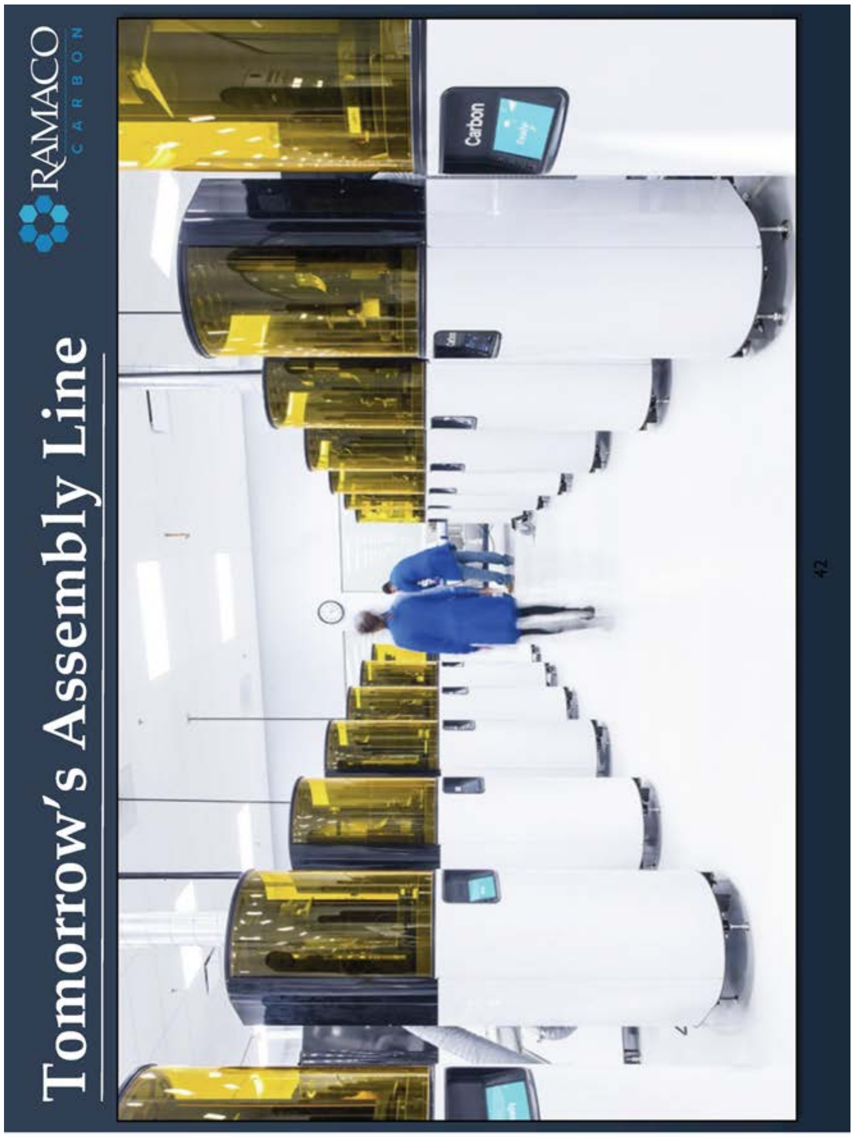
Memristor computer memory devices
- Emerging memory technology
- Energy efficient (<pJ/operation)
- High speed (10 ns)
- Easily miniaturized (10 X 10 nm)
- Integrable on logic chip

Coal carbons outperform other carbons and metal oxides
- Lower cost fabrication method
- Improved device-to-device reproducibility
- Better long-term device stability

Coal Materials: Engineered Graphene Quantum Dots


Coal to Resins for
3D Printed Advanced Products
RAMACO
CARBON
Resin
$99 to
$300/liter
Produce Resins
from Coal
Brook Mine Coal
Current PRB
Price: $12/Ton
Wyoming iPark
SpeedCell Printers
More printers =
More production
41


Tomorrow's Assembly Line
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Carbon
42

China is Pursuing C2P Tech

- The amount of coal required for coal-to-products can be enormous. Per the IEA, China currently uses ~400+ million tons annually for chemicals, fertilizers and fuels.
- **China's current 5 year plan call for ~370 new CTL/C plants (one new plant a week).**
- Within five years China will consume over **~1 billion tons per year for coal to products**.
- That is roughly double the entire amount (~530 million tons) of coal estimated to be produced in the US in 2020.
- This is roughly the entire amount (~530 million tons) of coal estimated to be produced in the US in 2020.
- There are questions whether these new plants also have strategic military or other purposes. Note the state-owned Hengli $20 billion investment in a coal-to polyester yarn plant supposed for use in making clothing

43

The Path Forward: Key Points

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#1 The coal industry must innovate to transition to higher value uses than primarily combustion.

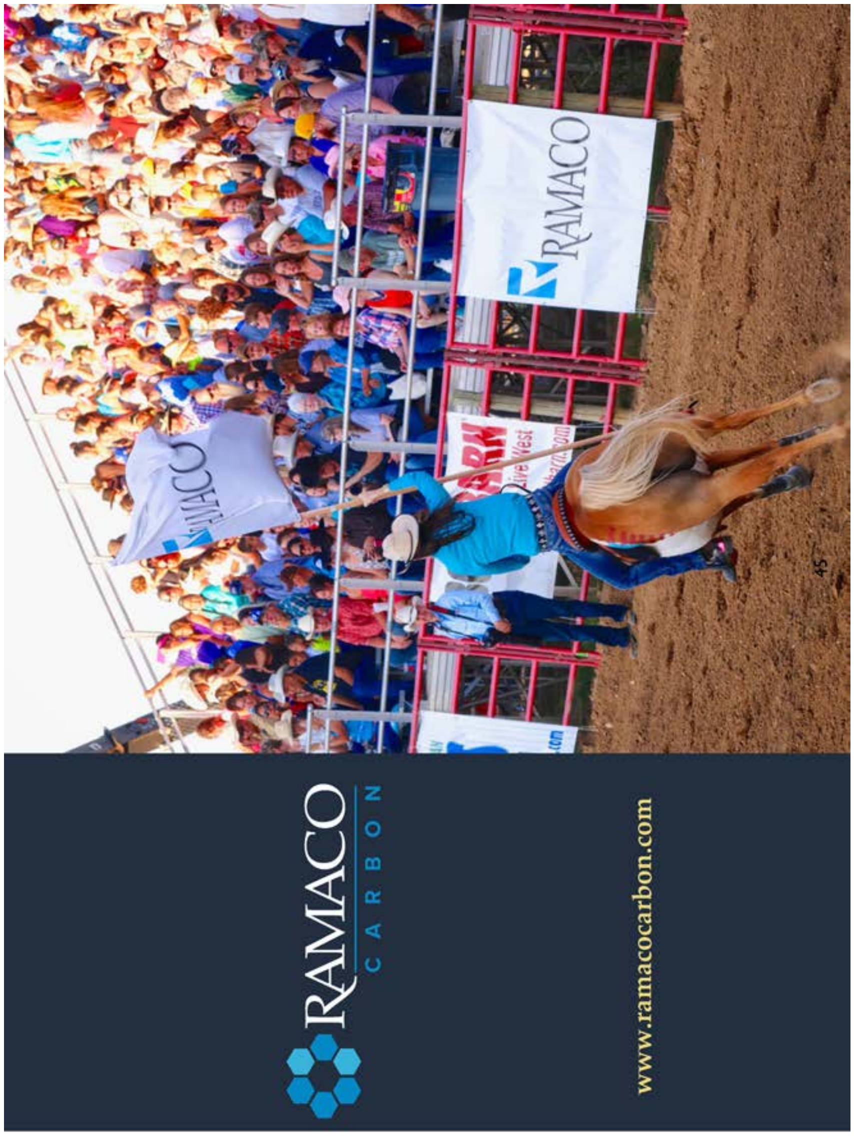
#2 The U.S. has both the carbon resource base and the technological prowess to fundamentally reinvent the industry.

#3 We have created the first vertically integrated **"carbon tech"** platform.

#4 "CAMP" manufacturing centers can offer a new path to repurposing older or existing coal communities and higher more sustainable long-term employment.

#5 Innovation and research is the first step. R&D must be leveraged, supported and nurtured in the broadest possible way at both the federal and state levels.

#6 Carbon Ore/Coal can have a dramatically stronger and environmentally oriented future than we can imagine. We just need to unlock the potential of carbon.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The CHAIRMAN. Thank you, Randy.

Now we are going to begin our questions, and I will begin.

This is going to be for all of you, and we will go down the line. We will start with Dr. Anderson and just go down the same as we did in speaking order.

The President, this morning, set an ambitious goal of 50 percent emissions reduction by 2030 which is extremely, extremely aggressive from where we had been before. I was glad to see specific inclusions of CCUS in the nationally-determined contribution, or NDC. As I said before, in order for carbon capture to thrive, we need to be thinking about the whole CCUS value chain, including how to use the captured CO_2 which is what you all have given your brief statements about. We really need to advance all the many technologies that put captured CO_2 to good use, whether that be in concrete, building materials, toothpaste or more.

The question would be, what do we need to do to get carbon utilization to the scale we need to be able to support and widely deploy the CCUS to help meet this ambitious, very ambitious, climate goal?

Dr. Anderson.

Dr. ANDERSON. Well, Senator Manchin, thank you for that question. I think that a lot of the direction or pathway toward meeting that goal comes to the reduction in the cost of carbon capture itself. So creating the low-cost feedstock of CO_2 through driving down the carbon capture cost. We have some aggressive targets. We're sitting at around \$40, between \$42 and \$48 per metric ton of CO_2 captured. We want to get to \$30 per metric ton of CO_2 captured to then provide that low-cost feedstock for the CO_2 utilization that provides another mechanism for providing market value.

Certainly, then continuing the efforts that we're working on and discussing today to provide options to create other vehicles for funding the carbon capture effort, I think, is also critical——

The CHAIRMAN. I just want to——

Dr. ANDERSON. ——cost of carbon capture and conversion.

The CHAIRMAN. Thank you. I want to make sure I clarify. There are people that will be saying that this is not feasible. We cannot get that type of reduction in that short period of time. That would mean you would have to eliminate using all fossil. I don't believe that. I believe that we do have the ability and we do have technology, if we are committed to investing in that technology rapidly and rapidly ramping up to meet this ambitious goal.

I think, Mr. Begger, if you could start now with your response. I just want to know if it is feasible.

Mr. BEGGER. Absolutely, we just need to be able to show at larger scales and I think that's where facilities like the ITC come in. I think another area that we need to consider when we're thinking about this is federal lands and permitting. If we're going to be doing geologic sequestration, a lot of that's going to happen on federal land.

The CHAIRMAN. And we have to accelerate our permitting process and not put all the roadblocks and go through the court process because it takes 10, 20, 30 years.

Mr. BEGGER. Absolutely, we need to be able to——

The CHAIRMAN. Okay.

Mr. BEGGER. ——move these things and permit them quickly. And right now, I don't see how you could go through an entire NEPA process to build a pipeline to seek out your CO_2.

The CHAIRMAN. Okay.

Go ahead.

Mr. BEGGER. I think that we need to think about the whole, the whole chain, you know, capturing, moving it, utilizing it in a place like Wyoming where we have such an extraordinary volume or amount of federal lands. The federal NEPA process certainly creates barriers when we'd look at things like where we've got the Dry Fork Power Station, to move that CO_2 to places where it can be used and utilized. So I think that's really important as well as the scale-up to demonstrate——

The CHAIRMAN. Okay.

Mr. BEGGER. ——that these things can work at a larger scale.

The CHAIRMAN. Okay.

Doctor.

Dr. SANT. There are three things I would touch on. Number one, I think we need to do large-scale commercial projects. We just cannot get away from this.

The CHAIRMAN. Can we scale up quick enough in order to meet these——

Dr. SANT. We can. What it would require is funding and, sort of, willingness to go there.

The CHAIRMAN. Okay.

Dr. SANT. The next thing that we'd really need is we need the creation of markets, and I think this is where the government can play a really significant role.

The CHAIRMAN. Okay.

Dr. SANT. We need "Buy Clean" purchasing mandates to really come about.

The third thing that we need is we need permitting, and we need permitting not simply for sequestration but also for utilization. And if we can couple this with the right kinds of incentives, particularly tax credits and direct payments where we couple, as an example, carbon reduction goals with energy efficiency improvements or production efficiency improvements, there's much higher incentive to actually make a difference.

The CHAIRMAN. Thank you.

Doctor. Mr. Atkins.

Mr. ATKINS. Sure, Senator. I think if you're going to approach this problem with that kind of a timeframe, you almost have to look at this like a Manhattan Project.

The CHAIRMAN. Correct.

Mr. ATKINS. Where you're going to devote a lot of resources from the federal and state level to try to accomplish something to really change both the market dynamics and the way a lot of things that we now take for granted are done differently, one of which, of course, that I focus on, of course, is coal. So if we could have a dramatically larger shift away from necessarily using coal for power production and use it for a non-greenhouse-producing function such as products, that would have a dramatically positive effect. And I think a number of the items talked about from both tax policy as well as funding for research are important components.

The CHAIRMAN. But I like that challenge. With that being announced today, we want to make sure that we are part of the solution, not an obstacle. And those of us who come from fossil states know, if the Federal Government is serious about this, they have to put their money where their mouth is.

I would like for all of you all to be thinking about this as quickly as possible and get a report back to this Committee on what it would take and the sort of investments that will be needed and the practicality of this being done by 2030. That would be very helpful to us. Okay?

With that, I am going to turn it over to Senator Barrasso.

Senator BARRASSO. Well, thanks so much, Mr. Chairman, and thank you for your ongoing leadership and interest in all of this.

Mr. Begger, one of the hallmarks of American ingenuity is our freedom to innovate. Do you agree that innovation is a much better way to address climate change than regulation and taxation, in effect, that the United States is only, at this point, producing about 15 percent of the global emissions and India and China are producing—their numbers continue to go up even though our emissions have been, over the last decade, decidedly down?

Mr. BEGGER. Ranking Member Barrasso, I think you're absolutely right. I think if you can innovate and find market solutions that people rapidly adopt and take, you're going to find the process moves a lot faster than the stick of regulation where you have to try to fit that round peg into that square hole.

Senator BARRASSO. Mr. Atkins, you know, your National Coal Council report discusses the cost advantage of coal-derived carbon over existing petrochemical feedstocks. With supply chains for petrochemical feedstocks pretty well established in the United States and around the world, how can we develop robust supply chains for coal-derived carbon here at home?

Mr. ATKINS. Thank you, Senator.

Well, as I pointed out, there is really a dramatic cost advantage to coal. So there's the same amount of carbon basically in a ton of coal as there is in a ton of petroleum, except a ton of coal in Wyoming goes for $12 and a ton of petroleum goes for about $400. So you start right there with a distinct advantage.

For the United States, we basically have the entire value chain and supply chain within our grasp. We have the resources. We have the talent. We have the mining talent. We have the technology talent. We have transportation and logistical advantages in coal-producing areas. If we can take advantage of those, that gives us a great deal of a head start toward trying to get those goals.

Senator BARRASSO. And then for all of you, and might be able to start with you, Jason, and then work our way all the way through.

In recent years, financial institutions have considered something called non-financial factors, including environmental, social and governance, when making investment decisions. Do each of you believe that financial institutions should consider carbon utilization technologies to be specifically compliant with these environmental, social and governance considerations?

Mr. BEGGER. Ranking Member Barrasso, absolutely. You know, if the goal is carbon reduction it shouldn't matter the flavor of carbon reduction and should be applicable.

Senator BARRASSO. Dr. Sant.

Dr. SANT. I agree. I think it's extremely important that we factor financial considerations into carbon reduction because if we think about the fact that, you know, we want to be able to decarbonize, we need technological pathways. And if those imply a cost, they also imply a cost not only to companies, but also the financiers that finance companies.

Senator BARRASSO. Mr. Atkins.

Mr. ATKINS. Yes, Senator.

Well, I spent a lot of time working with the financial community and I would agree with you. They should follow those and if they follow the science and the facts, they both would say that every molecule of carbon that is put into carbon product, is one that is not put in the air. So I would totally agree with that.

Senator BARRASSO. And Dr. Anderson.

Dr. ANDERSON. I would concur. I certainly agree that what we're trying to tackle is the emission challenge and we need to have all the levers at our disposal.

Senator BARRASSO. Mr. Atkins, using carbon and carbon dioxide as a feedstock in products, I think it is going to draw a lot of interest from consumers for environmental reasons. Yet these products really need to perform in a way that they could be priced competitively with existing products in the market. It is something that Senators Murkowski, Manchin, Cantwell, Whitehouse and I saw when we discussed these earlier research projects being done. How do products made from coal-derived carbon compare with existing products in the market?

Mr. ATKINS. Well, first of all, they are both cheaper. They are qualitatively better and, in many cases, they're stronger. As I mentioned, you know, coal enjoys a dramatic cost benefit over petroleum. So that starts the ball rolling, if you will. But when you get into some of the specific product lines, there's dramatic qualitative differences that improve the use of coal over petroleum in a number of these products.

Senator BARRASSO. And then, finally, for Mr. Begger. Coal communities in Wyoming, West Virginia, and other states have powered this nation for decades. The demand for thermal coal in the United States has been in decline, maybe for the foreseeable future. To what extent can coal-to-products manufacturing offset the economic and job losses in coal communities?

Mr. BEGGER. Senator Barrasso, I think for a lot of those communities it's about keeping up volume, you know, a community that's built on a 300 million ton per year sort of economy or a community that has a million ton per year mine, what can you do to do things at volume? And so, these products and projects and things that we do, I think we need to think about that to ensure that you saw the number of jobs and service organizations or companies and everything supporting that industry. So there are applications and opportunities, but we also need to think about what the number of people that it would take to carry out those new industries.

Senator BARRASSO. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator.

Now we will go to Senator Heinrich.

Senator HEINRICH. Thank you, Chairman.

I want to talk a little bit about the declining cost curves and one of the things I have learned—having grown up in a utility family, my dad was a IBEW lineman at a time when all of our generation was coming from coal and hydro—is that not all technologies decline in cost over time. And if you look at a coal-fired power plant, a thermal plant, or if you look at a nuclear reactor, because they have high labor costs, they have high permitting costs, they have a lot of uncertainty in their construction, oftentimes, but they tend not to decline over time. That is one of the reasons why we have struggled keeping our nuclear fleet going even though it is firm, carbon-free power.

So what I want to get at is like how do we, how do we, why should we believe that we can push the cost of carbon capture and sequestration down when many of these projects have more in common with a thermal plant or a nuclear reactor than they do with an iPhone or solar panel where you have clear manufacturing-based cost declines?

Mr. Begger, you look like you want to jump on that.

Mr. BEGGER. Senator, I think that's why we need to have a suite of technology options available. I think when we think post-combustion carbon capture, the ones that come to mind are, you know, Petra Nova, Boundary Dam, which actually employ solvent-based liquid. And there's actually a pretty significant, almost chemical plant that you build alongside that to, you know, to conduct the heat reaction and capture and do all those things, but there are other types of carbon capture technologies out there. For example, we have a membrane technology, just think reverse osmosis water. I mean, we, it can capture about 75 to 80 percent of the CO_2 by utilizing a membrane.

Senator HEINRICH. And would you describe that as more of a distributed technology than a big centralized piece of technology like, say, you know, the Kemper County facility that failed after so many years of cost overruns and construction delays?

Mr. BEGGER. The promise of something like a membrane technology is it can be modular.

Senator HEINRICH. Yes.

Mr. BEGGER. So, you know, you just add on more modules as you need.

Senator HEINRICH. That is actually one of the reasons why I am optimistic about direct air capture is because it is also a modular technology. It does not have to be centralized.

And so, Dr. Anderson, I wanted to ask you if you could speak a little bit about the role that NETL's planned Direct Air Capture Center can play in pushing this forward as well.

Dr. ANDERSON. Well, thank you, Senator Heinrich and if I might take the real quick time. We have also shown some considerable cost decreases over the last few years in carbon capture from point sources so moving to second generation technologies beyond the aqueous and mean solutions that Mr. Begger was speaking to. We've driven that cost down into the 40s when it started in the 70s. And so, we, we're seeing those cost declines and seeing some serious promise.

With regard to direct air capture, there are segments of the economy that are extremely hard to decarbonize. And so, when we get to those segments of the economy in the industry and furnaces in folks' homes and we need negative emissions technologies like that——

Senator HEINRICH. I am going to stop—I would agree with you when it comes to decarbonizing industrial processes. In most cases, furnaces in people's homes can be replaced with electric heat pumps and that is the most efficient way to get to zero carbon is to power those electric heat pumps with clean electricity.

But Dr. Sant, before I run out of time here, I wanted to give you a chance to talk a little bit about how you would structure a "Buy Clean" incentive for the U.S. Government to procure, for example, low-carbon concrete.

Dr. SANT. Senator Heinrich, really the important thing I think we want to fully focus on when we think about "Buy Clean" is we want to think about cost and we want to think about carbon intensity. Historically, with construction projects we've thought about everything based on the lowest bid and the lowest bid is an insufficient basis of procurement. We need to think about both cost and carbon intensity on an equal basis and potentially even on somewhat of a favored basis toward carbon intensity to create the market for low-carbon products.

I think, you know, of course, all of this imagines that you've got exactly the same engineering requirements that all products fulfill, but you use cost and carbon intensity as two levers that you can essentially adjust in making purchasing decisions. I think states like California are already moving forward with ideas of this sort, and you're starting to see that there's a response. Markets are starting to be thoughtful and most importantly, consumers, even at an individual level are starting to be thoughtful and I think that that's really how you capitalize change.

Senator HEINRICH. I'd be very interested in working with you on something of that sort. I do believe that, you know, the power of the Federal Government through procurement to really be a huge entry into transitioning these technologies to a much lower cost, to a much wider application, is part of how we solve some of these challenging problems.

Dr. SANT. So I agree 100 percent and this is important not simply to think about how we think about a bid process, but it's important for how we catalyze production capacity and market demand. And you know, both of these, all of these things have to work hand in hand because you need policy and manufacturing capacity and really consumer response to all sync together. And so, thinking about really good policy around it is important and we're happy to help.

The CHAIRMAN. Thank you, Senator.

Now we have Senator Lankford.

Senator LANKFORD. Well, thank you very much for your engagement in your research on all these issues. I do want to be able to dig a little bit deeper on how far we are on some of this research. This really is a question for Mr. Atkins and Mr. Anderson.

Tell me how close are we to being economical on trying to get rare earth minerals out of coal? Where are we? I know we are working on it a lot. We have talked about it a lot. Tell me, how close are we to making it economical?

Dr. ANDERSON. So, Randy, would you want to start or me?

Mr. ATKINS. Sure. We are now working with NETL's offices in Albany, Oregon, on assessment of rare earths and trying to essentially map out in the United States where rare earth deposits might be found. And the second part of the question, of course, is once we find them, how do we economically process them? I would say that in terms of finding them, we're much further advanced than we are, necessarily, in how we process them. And I think that's where, probably, a lot of research needs to be devoted.

And Brian, probably, since NETL is at the forefront at a lot of rare earth research efforts, I'll let you speak to the processing side.

Dr. ANDERSON. Sure. Well, Senator Lankford, I can get you the exact numbers and where our projections are today. We have a number of projects from different types of feedstocks, including raw coal, but also from some environmental remediation projects like acid mine drainage sludge which present a little barrier to the concentration of rare earths. We are not to the point of economical competitiveness with the international rare earth markets, particularly dominated by the rare earth deposits in China, but we are driving the cost down as we scale up the processes from a number of different feedstocks. I can get you the exact numbers.

Senator LANKFORD. That would be great.

Senator LANKFORD. I am not going to try to hold you to an exact number because no one knows the future but God, but give me a good guess on are we talking five decades, three decades, one decade, five years before we start getting to that point based on current trends?

Dr. ANDERSON. Based on the current trends, I think we're pointing toward a decade, but there's also some national security and implications of supply chain, supply chain variety. So, they'll have some domestic supply chains that it might be worth paying a slight premium to have domestic sources of rare earths and critical minerals.

Senator LANKFORD. Well, it is exceptionally beneficial to us to not be dependent on a communist nation like China for our rare earths, all of our development. Our rare earths and critical minerals are used in a lot of places and we are exceptionally vulnerable at this point and dependent on a communist nation for our basic supply chain, I think, is a terrible idea. And so, developing domestic sources, I think, is exceptionally important and this is an area that we need to continue to be able to engage in.

I do want to ask Mr. Anderson the next follow-up question on commercialization. There has been a lot of conversation about continuing to be able to use carbon in road building and a lot of other projects, building materials. Some of those are in current use and they are common. Some of those are exploratory and we may have a while on. So give me something that is aspirational at this point that is being discussed, but is not ready for prime time yet and give me something that is currently being used and is economical.

Dr. ANDERSON. So one that's extremely promising is our coal-to-graphene materials for additives in cement. We've been able to drive down the cost of producing graphene by over 10,000 compared to the current value which would enable high volumes of graphene to be produced and put into cements that strengthen cement for transportation applications. That's one that's aspirational but we see a real pathway into the future. Some of the other areas that are being at the edge of being put in the market that are some of our work in building materials, as represented by some of the folks here today, as well as Semplastics. I mentioned the Semplastics and X-MAT project that has built a facility in southern West Virginia to make roofing tiles that are a replacement for existing ceramic roofing tiles that is on the verge of commercialization and scale-up at the commercial scale with some tremendous success.

Senator LANKFORD. Great——

Mr. ATKINS. I might add on top of Brian's comment is that carbon fiber is another area that, I think, is going to be very critical which is close to something that we might be able to have into the market within the next two to five years.

Senator LANKFORD. Great.

Mr. ATKINS. And it has a dramatic impact on infrastructure. It has a dramatic impact on lightweighting of vehicles, on planes, on military and other strategic interests and that is an area that we've been working on with Oak Ridge National Labs which is something that we feel should be promoted by the government.

Senator LANKFORD. That's helpful.

Mr. Chairman, thank you very much for the time.

The CHAIRMAN. Thank you, Senator.

And now we have Senator Cortez Masto by WebEx.

Senator CORTEZ MASTO. Thank you, Mr. Chairman, and the Ranking Member.

Dr. Anderson, let me start with you. In your written testimony you stated that the emergent field of CO_2 utilization encompasses many possible products and applications and then you went on to list geothermal energy as a complementary technology, cutting-edge research in carbon utilization. As you may be aware, Nevada is one of the largest geothermal energy producers in the country and I believe we have significant untapped potential. Can you please expand on this and talk more about the ways in which both DOE and NETL are pairing carbon utilization and geothermal technologies?

Dr. ANDERSON. So our early research in the national labs back in the 1980s were identifying CO_2 as a potential geothermal fluid for use in engineered geothermal systems in the subsurface. It has some advantages over water because of its ability to carry energy and have lower viscosity and see it in geothermal applications. It is one that is still an active research area. There has been limited, limited field testing of using CO_2 as a geothermal fluid but the Geothermal Technologies Office and Energy Efficiency and Renewable Energy has continued to do some work on this. And in fact, in my own history as a researcher, I personally have done research in CO_2 as a geothermal fluid and it does have a tremendous potential to be coupled with regenerated, the mean regeneration facilities and the need for heat, to use CO_2 in the subsurface, produce geothermal energy and subsequently decarbonized through utilization.

Senator CORTEZ MASTO. Thank you, Dr. Anderson.

Let me ask Dr. Sant, in your written testimony you called for the need to stage support and incentivize deployment CO_2 utilization technologies in order to help industry transition and reduce CO_2 emissions. So as the U.S. invests in carbon dioxide technology, how should we be looking ahead to ensure that domestic manufacturing and workforce training is keeping pace with the innovation?

Dr. SANT. Thank you, Senator, for the question.

So, really, I think there's two or three things that we need to think about. You know, historically we've had a big focus on funding research and technology development to what, I'd say, is lower TRL [technology readiness level], so to speak, and we need to really look at pushing up the TRL levels that we offer support to. So I think, you know, when we think about manufacturing, we need to think about really the funding of full-scale commercial plants which allow us to do two things. Number one, they allow corporations to gain experience with operating and managing these new facilities and new processes which are different from what they've historically done. I think what goes hand in hand with that is really the retraining of a workforce because, you know, you need a workforce that's going to do things differently that have been done so far.

All of this can really only come about if we really funding the construction of these facilities and really putting them in place fast enough because without having the early-stage support that's needed to really have full commercial deployments, we're not going to scale up fast enough. And I think this kind of, sort of, operational familiarity, experiential familiarity, really comes from the government stepping in to offer early-stage support because as it builds experience, or builds experience not only in the production but also in the products and these things will go hand in hand with worker retraining and, sort of, broader technology diffusion into the market.

Senator CORTEZ MASTO. Then when you talk about, because I do believe there is an importance here with the public-private partnership that is essential in helping deploy these technologies and ensuring that the industry is trained and prepared. So that is a key component of design. I am assuming, as you are thinking about this, when you talked about government, kind of, stepping in, in the initial stages and incentivizing, but there is also this reliance on that public-private partnership. Is that correct?

Dr. SANT. Absolutely. All of these things have to follow a public-private partnership and it has to go up and down the value chain, right? So we have to think about manufacturing, but we also have to think about the creation of these products because having facilities that produce products that don't get used is not useful. And this is really where, you know, being able to stage, sort of, a "Buy Clean" type of idea where you really have these facilities that are producing products that go fulfill a "Buy Clean" agenda, sort of, gives you complete coverage of the supply chain and the value chain. I think being able to sync these things together, obviously, requires government support which is the public part and bringing private corporations to a point that they're able to, sort of, really leverage that support in the best way to really create a market for products and services which are of a low carbon nature.

Senator CORTEZ MASTO. Thank you.

Thank you, Mr. Chair.

The CHAIRMAN. Thank you, Senator.

And next, we have Senator Cassidy by WebEx.

Is Senator Cassidy on?

If not, we will have Senator Murkowski.

Senator MURKOWSKI. Thank you, Mr. Chairman.

You know I love these hearings.

The CHAIRMAN. I knew you were ready.

Senator MURKOWSKI. But to be able to talk about the technologies and how we can utilize carbon. You know, for so long, we talked about carbon sequestration. Okay, that's good. We can put it back in the ground, but to be able to utilize it, to manage it, and to make good stuff out of it, is exciting. We had that great trip when we did our Arctic CODEL and had an opportunity to go to the University of Aberdeen and to see there what they were doing with the various products, but just again, better understanding what we can do with utilization.

I am going to start my questions off with you, Dr. Anderson, because I want to talk about something that I don't think has been discussed here yet this morning and that is the potential that we have for utilizing, whether it is algae or kelp or seaweed, but the focus on what the oceans can provide. I have legislation that I have introduced with Senator Whitehouse, the Blue Carbon for Our Planet Act, which kind of focuses on what is naturally captured and stored in the oceans or what could potentially be utilized on our deep seabed floors. But more interesting to me is to be able to look at something like kelp, be able to use that as that carbon sink, if you will, and still have a market for a pretty extraordinary product.

So I am interested in this kind of innovation in seaweed aquaculture. We are certainly seeing it in Alaska. The Center for Climate and Energy Solutions estimates that by 2030 algae-based products will be a $320 billion industry. And one of the advantages that I understand is that it does not require high-purity carbon dioxide feedback. It can be processed, converted to different products, everything from food for livestock and aquaculture feed to food products, chemicals, et cetera. So the question to you this morning, Dr. Anderson, and with all that you have been doing at NETL, do you think that, I mean, am I just dreaming on this, that this is a great opportunity for us but that, with the potential for algae and other seaweed-type matter, that we can economically cultivate and commercially scale to, whether it is fuel different alternatives, but create other valuable products? So your comments on what we might be able to do with these materials that are part of our ocean systems.

Dr. ANDERSON. Senator, over the past few years or even, really, the past decade, we have had a number of projects specifically along using algae and using aquaculture for the capture of CO_2. It's showing some promise, but also some challenges, as you were alluding to in terms of economics, the economics of capture and pushing the CO_2 through the aqueous system and the growth, the growth profiles of the algae. However, a project at the University of Kentucky is showing some significant progress on making higher value and it's not vitamins, but higher value additives for animal feeds out of the algae process as opposed to moving it into the fuel sector. So there's still a considerable amount of work, and the work we're doing at NETL as well as NREL on the using algae for CO_2 capture.

In addition, we have with NREL and ExxonMobil a three-prong collaboration where the attempt is to use the algae and bio-, aquaculture-based processes with both Exxon's expertise and scale-up. And so, it's in the early stages, but again, showing some promise, but no major economic drivers that I see at the moment.

Senator MURKOWSKI. Okay, well, keep working on it. We are working on our end as well.

You know, it is interesting because this morning I am joining a large group of members—I think, Senator Manchin, you are part of this—but the growing climate solutions legislation that is being introduced today. So there is a lot going on, I think, where we are looking at these new and innovative ways, whether it is producing building materials or whether it is food for livestock, but it is a good point for us to be at. So how we take that next step, lots of good work going on.

Dr. Sant, I want to congratulate you and your team for winning the Carbon XPRIZE, pretty cool. I guess the question that I would have of you, and I will direct this to you, Dr. Sant, is should the Department of Energy's Building Technologies Office be doing more to help, whether it is develop, test or certify the carbonate material? Should other organizations, like ASTM International, be part of this? You know, as we try to figure out how we go from getting the great ideas to real commercialization here, should our agencies be doing more in that regard, other organizations as well?

Dr. SANT. So, Senator Murkowski, thanks very much for the question.

There's really maybe a couple of different comments to make. Number one, I think it's important involving the Department of Transportation because they are over, above and beyond largest consumers of concrete in the United States. Being able to couple this with the Department of Defense for, again, obvious reasons makes sense because, again, the biggest users. I think if we can tie this in with an agency like NIST, as an example, you know, National Institute of Standards and Technology, I think it gives us a unified way to get, sort of, the biggest buyers and, obviously, the Standards agency and get them to all work together. And eventually, flow all of that down into ASTM. The Building Technologies Office has historically not looked at primary construction materials, at least as I'm aware. They've looked to things like building envelopes and energy efficiency, but not really of primary construction materials. I think really starting out with the transportation agencies is a good place to start because anything that's accepted by a transportation agency is typically accepted downstream into the construction sector.

That said, however, I think it's important to really think about setting unified standards. And you know, I think creating databases is really something which I'll keep going back to because there are two parts to this. One part is really the engineering performance. The second part is really the life cycle or environmental intensity of production and use. And we need to really harmonize both of these things together which is something that we've not done.

Maybe just as an aside, you know, going back to your earlier question as we know the oceans are the biggest sink of CO_2 in the world and beyond simply thinking about kelp, as an example, you know, there might be some interesting opportunities based on work that we've been doing over the last several years where there are interesting adjacencies where you can achieve carbon dioxide removal but also produce things like hydrogen in the process. And hydrogen, as you know, is a clean fuel, so there might be opportunities to really couple this even beyond just what I'd said is biological farms to maybe even energy sources.

Senator MURKOWSKI. Very encouraging.

Thank you, Mr. Chairman. I appreciate it and I appreciate not only the witnesses being here today but what you are doing to contribute and push out in these great areas of innovation. So thank you.

The CHAIRMAN. Thank you, Senator.

And now we have Senator King by WebEx.

Senator KING. Thank you, Mr. Chairman.

Sorry to have been late to this hearing. I was at an Armed Services hearing talking about entirely different, but nonetheless very serious, issues. What I am most interested in is timing. We are in a race and we are in a race that we are losing right now. Let's put aside utilization of the carbon that we remove and I want to focus on carbon capture in the burning of fossil fuels and carbon removal from the atmosphere which is ultimately going to be necessary if we are going to win this race because of the persistence of carbon in the atmosphere.

Dr. Anderson, give me some hard numbers. What are we talking about for when we have a carbon capture technology that, for example, would be cost-effective on any fossil fuel plant? And the second question is, how far away are we from being able to actually remove carbon from the atmosphere, not capture it in the process of burning fossil fuels?

Dr. ANDERSON. Well, Senator King, thank you so much for that question.

Right now, given 45Q and a real concrete price point and price incentive which is a bit analogous to the ITC or PTC tax credits on solar and wind, there's tremendous commercial interest today given the technologies where we are today. The driving down the price curve which I mentioned earlier, I do believe there is a potential for continued decreases in the cost curve requires getting it out into the commercial scale and the commercial sector needs those concrete financeable incentives to capture carbon. And so, 45Q is a step. The follow-on steps would be the price of carbon and those price signals that folks can go to the bank.

And so, in short, I'd say it's as fast as we can construct those projects that are applying to 45Q today and then as they are deployed into the market within the next ten years, we will be driving the cost of capture down and I think we will achieve a $30 price.

As far as direct air capture, it's much higher up on the price curve. And so, when it comes to the incent—the price paid for carbon whether it's a 45Q tax credit, we have a longer way to go to drive down the cost of direct air capture.

Senator KING. Do you think that, when we are talking about capture, that by the time that capture technology is cost-effective, we will be out of the fossil fuel, at least in the electric generating business? The President today is announcing a goal of 50 percent reduction in nine years. So it may be that the technology becomes available at a time when there are no more fossil fuel plants. Is that a possibility or will there always be fossil fuel plants?

Dr. ANDERSON. I believe because of resiliency and reliability issues and also considering the deployment curves of the non-fossil emitting electricity generation resources, as we move to higher and higher levels of deployment, we need on demand, firm power generating assets. And so, those assets will likely be fossil energy with carbon capture moving into the future. And we are in the midst of a lot of natural gas plants being built today and natural gas with carbon capture has a great potential of providing that firm power in a carbon-free basis with carbon capture.

Senator KING. I fully understand the importance of backup power and to solve the intermittency problem, but again, we are talking about a five- to ten-year timeframe we may see dramatic developments in storage or in a new generation of nuclear power which could provide that backup, but it is certainly a dynamic market. I am encouraged about the timeline on carbon capture. I am discouraged about the timeline on carbon removal because in the long run, that is going to be necessary. We could stop all carbon in the atmosphere tomorrow, and we would still have a problem. As you know, we are pretty much beyond the tipping point.

Dr. ANDERSON. Yes, and so that will, you know, perhaps we need different levels of the carbon incentive to make it economical for direct air capture or other carbon removal technologies.

Senator KING. Do you believe that a price on carbon in some way has—some kind of good carbon price and dividend would be an important policy initiative?

Dr. ANDERSON. Well, if we are to decarbonize our economy, we do need price signals that the private sector can run to the bank and are bankable in order to decarbonize. In terms of the policy mechanisms, there are a number of ways to get to the end goal, but some signal on carbon, itself, is necessary.

Senator KING. Thank you.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator.

Now, Senator Daines.

Senator DAINES. Thank you, Mr. Chairman.

Last Congress, we passed our bipartisan EFFECT Act. It increases investment and, importantly, commercialization of carbon capture technology. And while the U.S. continues to lead in carbon capture research, as well as development, we have not yet brought the technology to scale in the cost necessary for wide adoption. In the EFFECT Act, we set up a program for large-scale pilot projects at an existing coal or natural gas power plant. In fact, I believe that Montana is a great fit for one of these pilot projects. I have five letters of support from the community and businesses around the Colstrip Power Plant asking for a project to be located there to help keep and to grow the jobs in that area.

Dr. Anderson, as DOE prepares to implement the authorities in the EFFECT Act, what will DOE be looking for in a pilot project and how can we ensure that the voice of Montanans are heard in that process?

Dr. ANDERSON. Well, Senator Daines, thank you for that question.

As we move forward, the deployment of carbon capture and sequestration technologies under our carbon capture program, we have a number of projects under CarbonSAFE which has been identifying the subsurface resources available for sequestration. We're moving into a FEED stage, Front-End Engineering Design, which would do the full-scale design of the integrated carbon capture and sequestration process for a number of our CarbonSAFE FEED study projects and what we're looking for is that fully encompassed design and the implementation plan. Then when it comes to deployment in large-scale and being able to scale up to the commercial scale, again, I do believe that a lot rides on the signals like 45Q that would provide financing for the private sector to pursue carbon capture projects.

Senator DAINES. Thank you, and I appreciate your thoughts on that. I think that would be helpful. We have, we think, a wonderful place for it, of course. It is a large operation, transmission lines that take care of moving energy across the Northwest, so we would like to be considered for sure.

While it is important to promote federal investment in research and development, we also need to ensure companies have the tools in place to create and build those jobs. That is where Chairman Manchin's and my bipartisan American Jobs in Energy Manufacturing Act comes in. Our bill incentivizes companies to build the next generation of energy manufacturing in the U.S. and specifically in rural areas like Montana, and updating, of course, the tax credits. This includes clean technologies like carbon capture and utilization, renewable fuels and coal-to-products.

Mr. Atkins, how can companies like yours leverage tax credits like the one in our bill to create jobs in rural communities? I know they are very important to Senator Manchin and myself.

Mr. ATKINS. So I think tax credits are an integral part of any private financing. We look at trying to basically look at creating an equality with the 45Q credit so that perhaps there might be credits for not only just not using carbon emissions, but also capturing it. We've been working with NETL on some rather innovative technologies where we can take forest carbons, taking basically a gram of coal and we can create 3,000 square meters worth of porous surface. That can be used to capture carbon and that's the type of thing that we want to get private incentives from the government to be able to put into manufacturing in the private areas.

Senator DAINES. Yes, I think that is what sometimes is forgotten. It is a very capital-intensive process——

Mr. ATKINS. Indeed.

Senator DAINES. ——with long-term payouts. It is something that——

Mr. ATKINS. And in many of these technologies there's what's called the manufacturing valley of death where you essentially, you need, you know, vast sums of private capital to create manufacturing facilities to meet product ends which, in many cases, are incented by the government.

Senator DAINES. Yes, and I think then also it is the certainty that is needed for these long-term capital investments——

Mr. ATKINS. Indeed.

Senator DAINES. ——that would be most helpful. Thank you, Mr. Chairman. I yield back my time.

The CHAIRMAN. Thank you, Senator.

And now we have Senator Cantwell.

Senator CANTWELL. Thank you. Thank you, Mr. Chairman. Thank you to you and the Ranking Member Barrasso for holding this hearing. Happy Earth Day to both of you.

The CHAIRMAN. Happy Earth Day.

Senator CANTWELL. I certainly appreciate that there are many hearings across the spectrum today talking about R&D investments. Many of you know we are working on the Endless Frontier Act in the Commerce Committee, and we certainly want to get technology innovation and commercialization right. I think this particular area we are discussing today about clean energy markets and more R&D into carbon sequestration and utilization is certainly worth more investment. So I certainly appreciate that and certainly appreciate the role of DOE in making sure that it is recognized in the future and making sure that we continue to empower it on these areas.

I wanted to ask two questions. Mr. Begger, what do you think that we have learned from what you have been able to do in Wyoming as it relates to the ITC, Integrated Test Center, and activities like the XPRIZE—what do you think we should apply from that to the future public-private partnerships? I am also curious, to any of the witnesses, I think of our public lands, obviously, as a way to sequester some amount of domestic carbon emissions and what else should we be doing in that particular area? The National Academy of Sciences estimated the U.S. can store an additional 500 million metric tons of CO_2 per year through a mix of carbon-enhancing practices on crop land, grasslands and forest lands. And so, I think this is something that we also should be considering.

Mr. Begger, if you want to start and then anybody who wants to answer the second part?

Mr. BEGGER. Senator, I think we've learned a lot of really important lessons at the ITC, and we feel like we bridge that valley of death role that was just mentioned. And NETL and Department of Energy has a great graphic that, sort of, shows this timeline of technology development and there was this valley of death between the small-scale things coming out of laboratories and universities versus things at a 10- to 20-megawatt scale which is 200 to 400 ton per day of capture—facilities that industry needs to see in order to feel comfortable that it's scaling up. And I think that's the biggest thing with the success of the Integrated Test Centers, our utilities, and the National Rural Electric Cooperatives Association, is they're able to give us nudges, indications, as to hey, as ultimate consumers of this technology, these are things that make sense to us and fit in the economics of how we run our business. So I think that's important.

I think in other areas looking at environmental permitting, everything that goes along with it, as a research facility, each and every one of our tenants still need to comply with the Clean Air Act and receive permits and do things. So looking at things like a blanket permit waiver from the EPA for test facilities would be really helpful for teams like CarbonBuilt that came in that are academics that really have never dealt with permitting and things at that level of sophistication before that we had to help them with. And last, when you think about public lands, you're going to trigger NEPA, every step of the way, and I look at, we have a——

Senator CANTWELL. I don't know, why would you trigger NEPA? What I am saying, let's make sure we preserve big forests like the Tongass or other areas that don't de-carbon and don't take away from that, so——

Mr. BEGGER. Senator, I'm speaking a little bit more broadly with industrial uses, like you're moving CO_2 from, say, places that are sources in the Midwest to the West where you have really good geology for geologic sequestration, so——

Senator CANTWELL. I am talking about just understanding our current natural benefits. Anybody else on that point?

Dr. ANDERSON. So Senator, if I could——

Mr. ATKINS. One way to also look at this might be to consider, not just the public side, but the private side because if we can incent private industry to use other means of, sort of, separating the C and the O_2, we've proven that there are uses for the carbon. So I think there's more than one way to skin a cat and I think to the extent that Congress can help incent research and development from the private side toward this, I think, that might be very useful.

Senator CANTWELL. We heard another voice somewhere.

Dr. SANT. Senator Cantwell, I'm happy to say something about the XPRIZE. I think, you know, one of the things that we really liked about the competition and sort of just thinking about the general idea of innovation, being able to work toward a defined goal is always really good, but I think what's really required as we think about innovation is an acceptance for failure, right? I think we've gotten overly focused on, sort of, just, being, desiring success, but in innovation, success is never assured. And I think being able to accept failure and being able to build programs that, sort of, reward failure as a step in the learning process is, I think, something that we fundamentally need to think of as we approach large-scale R&D, especially the kinds of crash R&D programs that are likely to be needed to make a difference in a decade.

Senator CANTWELL. Mr. Chairman, if I could, on that point because this is so important to this broad debate that we are having today. I think there is a really big philosophical question that we have to address here. To me, if you are talking about the private sector having its experiments and having failures, I am all good with it, okay? If you are talking about us doing basic research and having failures, I am all good with that too. But if you are talking about taxpayer money and you are picking certain technologies as winners and losers and then finding out, or maybe even building actual test bed manufacturing facilities and you basically lose—I'm not sure taxpayers are good with that.

So I think that we want to proceed on some of these questions because as Mr. Begger said, the test bed in Wyoming did give us some answers and we are at that stage where we want to take tech transfer and make it more robust, but I guarantee, the minute we have a Solyndra or something like that, the public, the taxpayer dollar isn't going to be down with, you know, we failed. So I think we just have to get some context here. I am just trying to understand. What context are we going to have to the government funding actual, what I would call, translational science and having failures? I just do not know how to categorize that because now we are dealing with taxpayer money, not investor money. And I do think my constituents who are a very, very big innovation economy, I would say there are hundreds of thousands of people who invest in these companies in my state. They are very sophisticated, you know, they definitely understand risk. But I don't know that they understand that that risk could be taken with taxpayer dollars.

So if anybody can help me out on that, I would love to hear an answer because we are in the midst of trying to do this right now with this big EFA bill.

Dr. SANT. You know, I don't have all the answers. This is definitely an important point that we raise and, of course, we want to be good stewards of taxpayer money, for sure. But I think the reality is that, you know, not all questions can be answered until we get to full commercial scale. And I think that's just, sort of, the nature of the beast. I think between a combination of being able to deal with those technologies sequentially as we come up with TRL is something that we need to do, being able to develop really robust vetting processes that'll give us a line of sight, understanding if something might fail is an important thing to do.

But I think there's also a market aspect to it because, you know, if you create a market demand on the other side, it's highly unlikely that you would end up with failure because of this demand that assured and the supply that's coming online, that generally leads to a favorable outcome. And so, you know, I think, I think, I don't disagree that this is, sort of, a bigger and a broader issue, but we maybe need to think about it a bit more expansively, as simply just, sort of, a single case at a time.

Senator CANTWELL. Thank you. I know I am way over my time, Mr. Chairman, but this is such an important timely question and I do think it is important, particularly in this particular area too.

Senator BARRASSO [presiding]. Well, thank you so much, Senator Cantwell, for your continued interest in what we had talked earlier while you were here, you know, the traveling that we have done to look at some of these research projects that were done. And as Dr. Sant, who has actually won the award, the XPRIZE, where we had looked at the research done overseas. So thank you.

Senator Cassidy.

Senator CASSIDY. Thank you, thank you, all. Just putting time between hearings so if I ask something that is redundant, I apologize.

Dr. Anderson or Mr. Begger, my briefing materials spoke about carbon dioxide from a fluent, for example, or whatever, being used to create methanol. Another example was being used to make ethylene. What is the cost basis, do you know, of making methanol from CO_2 as opposed to that which is made from natural gas? I just say that because that relates to commercial viability. We want to have a wonderful—we want to have someplace to make, you know, to do with all this CO_2, some way to use all this CO_2 and I am just curious about that, nothing else but curiosity right now.

Dr. ANDERSON. Senator Cassidy, if I might jump in. You know, certainly because CO_2 is thermodynamically more stable, it is moving back up, back up the oxidation chain. So it is not more economical to go CO_2 to methanol than it is methane. However, under certain context because of—if, as we move down the deployment curve of intermittent renewables, there are times in which we may end up with curtailment situations under renewables with excess electricity and in terms of the storage options, there's battery storage for grid-scale, but there are also thermochemical storage opportunities. And so, if you couple an intermittent renewable generation facility with direct air capture, you might have a source of CO_2 that's effectively free and electrons that are, would otherwise be curtailed that would allow for the chemical storage.

And so, it's part of the integrated energy systems work that we have going on at Idaho National Lab and NREL to understand the full dynamics of those economics which are simply more complicated than just starting with methane or starting with CO_2.

Senator CASSIDY. Now does that suggest that you need proximity of the generation to the plant which is converting to direct air capture, for example, or can it just be excess electrons on the grid? And, just curious, can you have a start and stop, you know, kind of a rapid gear up? We are going to start taking your CO_2 and turn it to methanol, knowing that this may be TBD, but what you are saying is very intriguing to me.

Dr. ANDERSON. Senator, some is TBD and it certainly doesn't have to be proximal, but at least with direct air capture you can move it almost anywhere and you can eliminate line losses if you do put it proximal to the intermittent resource.

Senator CASSIDY. My understanding was that direct air capture works best in warm, humid environments. Coming from Louisiana, of course, that perked my ears. But are you suggesting that we could do just as well in some frigid, northern place beset by snow and ice?

Dr. ANDERSON. Well, it might not be as efficient, but there is certainly a demonstration facility in Iceland in one of the direct air capture demonstration facilities that's doing pretty well in Iceland, as well.

Senator CASSIDY. The ethylene—I see that there is a demonstration project with Occidental using CO_2 to make ethylene. Again, is that the same principle that you have been discussing?

Dr. ANDERSON. It is effectively the same principle. CO_2 to a syngas with water and then from syngas you can make almost any of the hydrocarbons.

Senator CASSIDY. Just a question of whether or not you have adequate energy input, whether or not your net carbon profile is better off with or without it. Fair summary?

Dr. ANDERSON. Well, absolutely, because you are climbing up the energy chain going from CO_2 to a hydrocarbon. And so, it requires some excess energy.

Senator CASSIDY. Dr. Sant, again, I apologize if someone has already asked you about this, but I think it is really interesting, your technology. If you use CO_2 to cure your concrete, how much does that save on your CO_2 profile relative to traditional Portland concrete—cement?

Dr. SANT. Senator, we've spent a lot of time looking at this and, you know, if I give you an example around something like a typical concrete block, which is one of the products that we're in the midst of producing, we can reduce the carbon intensity by between 50 and 70 percent compared to a traditional concrete. So it's a really, a pretty significant reduction.

Senator CASSIDY. I have been, you know, there are a lot of advocates for carbon taxes which it seems like if you are going to have a border adjustment tax or a carbon tax, you would have to take into account not only the energy inputs but also the concrete that would be required to build a particular facility, if you are really going to—as well as the vehicles going back and forth, all that sort of a thing. So if somebody was going to build a facility in the U.S. or overseas using your technology, the logical extension is if you have a border adjustment tax or a border adjustment credit, is that somehow this would be amortized over a certain period of time, the amount of carbon that they, that the constructors saved from using your technology. Again, I am thinking out loud, but I suspect you would agree with that?

Dr. SANT. So generally speaking, you know, so, of course, a border type of adjustment may or may not make sense depending on whether you're dealing with an import question or not, but I think the short answer really turns out to be, it really depends on the price signal on CO_2 and whether that price signal is best valued over an amortized basis or whether it can be recovered at the front end. If you can recover it at the front end, I think you want to do it all up front. On the other hand, you know, if there's a reason to sort of make a bet on the forward price curve, well then you might choose to amortize it so you can essentially value it into the future.

Senator CASSIDY. All, I appreciate your testimony. I yield back, Mr. Chairman.

The CHAIRMAN [presiding]. Thank you, Senator.

Now we will have, Senator Marshall.

Senator MARSHALL. Well, thank you, Chairman.

My first question is going to be for Mr. Atkins and it has to do with the tax benefit that, I believe, both the oil and gas industry and the coal industry benefit from called the percentage depletion allowance. One of the prerequisites here is that coal is a very cheap product and there are so many opportunities for it, and it is my understanding in the infrastructure bill that is coming before us that we are considering, that we would lose this percentage depletion allowance. When I think about tax benefits that the different energies receive, I think about the oil and gas industry, coal industry—if it was 1 time, probably the wind energy receives 7 times that, and solar maybe 70 times that, from a benefit from the Federal

Government. And I always preface this by saying, look, I want to leave this environment cleaner, healthier and safer than I found it, as do all of us in the room, but I cannot drive the cost of energy up so much that a working family can no longer put gas in their car or pay their electricity bill.

Is that, am I making some reasonable assumptions here when you think about tax benefits to the different industries that really coal, this may be the last thing standing that coal gets?

Mr. ATKINS. Yeah. I think, you know, all industries like to play on an even playing field and I'm afraid, you know, as we've gone on over time, that playing field keeps changing. Obviously today, the thumb on the scale is obviously weighted toward renewables. It's been taken off of any of the fossil fuels. And I think the way we've tried to approach it, obviously, we are in favor of all incentives that can be given for any form of production in this country. I don't care whether it's wind, solar, coal, fossil fuel. They all create jobs. They're all critical to our national strategic interests and they should all be fostered.

What we've tried to do is to, sort of, take away from the equation, you know, the notion that somehow carbon is bad. Carbon is not bad. There are issues, obviously, when you combine a carbon with an oxygen molecule and you have CO_2. And we understand that. So we're trying to basically move beyond that thesis and really step outside into something modestly transformational where we say, all right, let's look at the carbon inside of something that is, today, in disfavor, frankly, and see if we can turn—I hate to use this phrase—sort of, a diamond in the rough.

[Laughter.]

So, you know, coal is a—a diamond is basically coal that's done well under pressure. So essentially, that's what we're trying to do.

Senator MARSHALL. Yes, coal gives us a pretty big bang for the buck when it comes to energy. There is no doubt about that as well.

I think my next question is for Dr. Anderson. Dr. Anderson, we are hearing about more technologies here today and taking carbon and just turning it into some incredible things from a manufacturing process. And I had the opportunity recently to sit down with a company, Carbon Solutions–Materia USA out of Pennsylvania, and they gave me a piece of carbon and then gave me the fiber that they are able to turn it into and the graphite as well. I mean, I think it could be transformative. When we think about the opportunities for high-speed fiber, making carbon into high-speed fiber, making semi-conductors, my goodness. Other countries are dominating all these areas and we have to bring these back to the United States.

So, Dr. Anderson, I guess my question, you know, are you committed to helping the Department of Energy bring these technologies to fruition and help Americans out here, bringing these supply chains back into the United States?

Dr. ANDERSON. Yes, we are. And in fact, I think that there is one, one opportunity here that we may not have stated. There are many communities across the country, coal and power plant communities that are, have been impacted and will become even more impacted as we move forward in the energy transition. And as we create opportunities for adding value from the coal resource that are in these coal communities, it turns out that many of the supply chains are much more efficient if the processing facilities are moved closer to the mine mouth.

And so, in fact, when we look at the replacement of jobs that Mr. Begger was alluding to earlier, there is an opportunity to add value, like you were mentioning these high-value products, by bringing the supply chain back closer to the mine mouth and creating additional jobs in addition to replacement of tonnage, as was spoken of earlier.

Senator MARSHALL. Is there anything more specific that you can describe what you see the role the Department of Energy is in bringing this to the real world?

Dr. ANDERSON. Well, and so, it is as one, an applied laboratory and the government-owned, government-operated laboratory within the DOE that manages the program across fossil energy, energy efficiency and renewable energy and CESER and OE. It is our job to make sure that these technologies find their way into market and reduce risk and have the appropriate technology transfer pathways for all the technologies we work on, including coal-to-products and the other carbon products and CO_2 utilization. So it is firmly within our mission to try to get these technologies into the hands of the folks who will put it into a commercial practice.

Senator MARSHALL. Thank you and I yield back.

Senator BARRASSO [presiding]. Thank you, Senator Marshall.

Senator Hoeven.

Senator HOEVEN. Thank you, Mr. Chairman.

Dr. Anderson, how important is collaboration between NETL and its partners like the Energy and Environmental Research Center, EERC, at the University of North Dakota in terms of developing the technologies that are going to help us crack the code on carbon capture and sequestration? Could you talk a little bit about the importance of those partnerships and your commitment to them?

Dr. ANDERSON. Yeah, so importance, in general, is where we live. We have over 600 partners across the country, but there are some that are committed and share a mission with us, including EERC. And so, the EERC in North Dakota is really critical to a number of our technology developments across rare earth elements, gasification, coal-to-products, unconventional oil and gas as well, and certainly, last but not least, in CO_2 sequestration. And so, there are, you know—partnerships is really the name of the game for us because it takes the entire value chain and skill set of folks across the country to work and tackle these challenges.

Senator HOEVEN. And, are you confident that we can crack the code on carbon capture and storage from our coal-fired electric plants and that it is an important part of our energy mix?

Dr. ANDERSON. I am confident. The EIA, well, EIA and the United States, and the IEA internationally, time and time again have shown that if we're going to decarbonize our first electricity sector and the economies, we need the technology of carbon capture and utilization and storage. And so, it will be a critical component to our pathway to decarbonizing the economy.

Senator HOEVEN. And not only, if we, I mean—and make it happen in this country, then the rest of the world will be adopters too and there is a lot of coal-fired electric in other countries. So that is a huge factor of it.

Dr. ANDERSON. Yes, absolutely agree.

Senator HOEVEN. Thank you very much.

Mr. Begger, in terms of trying to help make this happen in terms of cracking the code on carbon capture, we have worked on help through 45Q, the tax credit for geological storage. We have worked on the loan guarantees through DOE and RUS (Rural Utilities Service) and we have worked on funding help from DOE for the equipment that needs to be put in place to make it happen. Those are the kind of incentives and programs we are trying to bring to work with our industry and the states to make this happen. Tell me your view on how we continue to enhance those tools to make CCUS happen.

Mr. BEGGER. Senator, I believe we need to make sure that we have the infrastructure in place within the U.S. to actually support these technologies. You know, I mentioned earlier that for large-scale technologies above, you know, really a megawatt, a megawatt and a half, to scale up to that 10 to 20 that people see, we send technologies and U.S. taxpayer dollars to Mongstad facility in Norway. We have that ability in the U.S. We should be building up facilities—two, three of those that can do that here. It's all about scalability and access. For a lot of smaller technology developers, they may not have access to, you know, the National Carbon Capture Center or EERC, so what are we doing to put the tools, or sort of grease those skids, grease that glide path to technology development? And I think a critical part of that is not just the programmatic funding to do the things that we need to do, but the bits and pieces on the back end to provide that platform for these technologies to scale.

Senator HOEVEN. How important is it that we get, that we enhance 45Q with the direct pay option?

Mr. BEGGER. Senator, I think it's going to help really be a game changer. Right now, you know, for 45Q if you're going the tax equity financing route, you're only going to see a fraction of that. So $35 for EOR, you know, I don't know what the exact market is, but it might only be $17 or $18.

Senator HOEVEN. Right.

Mr. BEGGER. So making sure that that money actually ends up in the hands of the developers and the people moving the project and not the financiers, I think, would be really important.

Senator HOEVEN. Yes, for that direct pay option 45Q the CBO score is less than, the ten-year score is less than a billion dollars. And that, as you said, would be a game changer, right?

Mr. BEGGER. That's correct. Just a week ago I was speaking with a large EOR development company and just looking, they were kind of walking through their thought process and how they value and look at projects and they go, you know, a $5 to $10 differential is more than make or break, it's really are these things profitable or not? And they said the direct pay option would be something that could make up that gap.

Senator HOEVEN. Yes, absolutely.

Thank you so much, I appreciate it. Thank you, Mr. Chairman.

The CHAIRMAN [presiding]. Thank you, Senator.

I think we have Senator Hickenlooper.

Senator HICKENLOOPER. Hey, how are you doing?

The CHAIRMAN. Good.

Senator HICKENLOOPER. Sorry I am a little bit late.

The CHAIRMAN. No problem. Wrap it up.

Senator HICKENLOOPER. I think this is a great panel. I have been dodging in and out so if I am asking a question that is redundant, I apologize. I think having so much thought about carbon utilization which, obviously, has the potential to be a giant market opportunity, but at the same time we are working to build our capacity to permanently store CO_2 underground.

Dr. Anderson, the National Energy Technology Laboratory, if we are awarded funding in Colorado to capture emissions from a cement facility which could then store that CO_2 permanently underground, how should we be thinking about the relative value of permanent sequestration versus the CO_2 utilization we have been hearing about today?

Dr. ANDERSON. Senator Hickenlooper, thank you for that question.

I think that, you know, the value of decarbonizing the economy seems like, you know, one carbon avoided into the atmosphere has its own inherent value, but as we drive down the cost of the carbon removal and create the markets because of the availability of low-cost CO_2. CO_2 is not free today. And there are opportunities then to utilize it into other products that are also permanently sequestered. And so, one of our, you know, from our standpoint, one of the big areas for us in our research program in subsurface sequestration and permanence is to drive down the risk of permanence as well and we have a multi-laboratory consortium called the National Risk Assessment Partnership to help drive down that risk for the surety of the permanance of CO_2 sequestered in the subsurface.

Senator HICKENLOOPER. Yes, and I love that collaborative effort that you have on so many of these.

You have talked a little bit about the 45Q tax credit to provide a revenue stream for capturing carbon so as to incentivize the development of this, of these technologies and to move us closer to getting to carbon free—or achieve negative emissions, I guess you would call it. What effect would it have—and a lot of people are talking about some sort of a price on carbon, let's call it a fee and dividend but it could be any of a variety of proposals—how would this help accelerate that emerging field of carbon utilization?

Dr. ANDERSON. Well, I think that with the 45Q, and I made an analogy earlier that it is a bit more similar to the investment tax credits and the production tax credits that we see on renewable deployment. And so, I think that as part of a whole portfolio of incentivizing the movement and deployment of the new technologies on the market, like 45Q does, like the ITCs and PTCs do, it is really important to help incentivize that movement into the market. And then, if there is long-term certainty that can create the financial incentives, and we did have a discussion with Mr. Begger just recently regarding how some of those payments will go straight to the developer, but at least some certainty around the future of carbon that will provide the long-term incentives of large-scale investment for CCUS is really important.

Senator HICKENLOOPER. Yes, yes, exactly.

Mr. Begger, you talked earlier about some of the issues around capturing CO_2 and I am, you know, this notion of carbon sequestration which seemed, you know, a long shot not so many years ago, clearly can be done and the cost continues to come down. There are also infrastructure needs associated with capturing CO_2 and transporting it to permanent sites or locations for reuse. Can you speak to the job growth and economic opportunities associated with the buildout of this kind of infrastructure?

Mr. BEGGER. Certainly, Senator.

You know, you just look at what it would all entail. I mean, really the management of carbon is taking it from sources and putting it toward sinks, you know, and the sinks can be a lot of different things, whether it's, you know, geologic sequestration, enhanced oil recovery, to products. But that's, the process is we need to be able to capture it and move it, you know, and capture could be on a power plant, it could be direct air capture. I guess I'd look at it in terms of, you know, in any other sort of industrial project. Certainly, a buildup of an industrial facility could be many thousands of jobs. Then you look at pipelines. I think it's pretty well documented the number of jobs that are associated with pipelines to move it from point A to point B. So, really, you know, particular projects is going to be thousands of people, so I think there's tremendous value in the buildout.

Senator HICKENLOOPER. Yes, well, I love the work that you guys are doing. Actually, all of you, I think it is a broad cross section. It takes me back to my—you know, I did do a research project, I guess 40 years ago, on using salt as a storage vehicle, salt formations as a storage vehicle for radioactive materials for carbon, for CO_2, things like that. Anyway, it is good to see that these things go in full circles.

Anyway, I yield back my time. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you.

Senator Barrasso.

Senator BARRASSO. Terrific hearing, Mr. Chairman. Let me thank you for bringing in these wonderful guests to talk about some of the most exciting research that I think is happening anywhere.

The CHAIRMAN. Well, thank you for bringing all the talent you brought from Wyoming too.

Let me just say to all of you, it really has been a great, great hearing. I want to thank you. But I am also challenging you all to tell us how quickly we can get to 2030s target date and what it takes if we start today to ramp up.

I am also very encouraged about those of us who have coal, areas where coal plants have closed or coal power plants have closed. This could give us a whole new manufacturing renaissance there. It really fits better rather than trying to go into a coal area and bringing some type of manufacturing that does not fit with the culture. So that is so exciting right now, but I really look forward to hearing from you all.

Members will have until the close of business tomorrow to submit additional questions for the record.

Again, thank you, each and every one of you.

[Whereupon, at 11:57 a.m. the committee adjourned.]

APPENDIX MATERIAL SUBMITTED

U.S. Senate Committee on Energy and Natural Resources
April 22, 2021 Hearing: ***Opportunities and Challenges that Exist for Advancing and Deploying Carbon and Carbon-Dioxide (CO2) Utilization Technologies in the United States***
Questions for the Record Submitted to Dr. Brian Anderson

[No Responses Received as of the Date of Printing]

Questions from Chairman Joe Manchin III

Questions: The President set an ambitious goal of a 50% emissions reduction by 2030 which includes the use of CCUS. As discussed in the hearing, meeting this target will require a developed, thriving CCUS ecosystem from capture to end-use, which includes wide-scale deployment of carbon utilization technologies.

1) Can you expand on your comments on what specifically is needed to commercialize and widely deploy carbon capture, utilization and storage technologies to help meet this ambitious target?

2) How can the wide-scale deployment of these technologies revitalize coal communities across the country?

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1) Can you expand on your comments on what specifically is needed to commercialize and widely deploy carbon capture, utilization and storage technologies to help meet this ambitious target?

The utility industry places a high premium on reliability and are extremely cautious about the impacts to providing service when adopting new technologies. CCUS technology is new to power utilities at power plants, but this is not new technology. So, the initial movers need support to make the adoption smooth and help mitigate risk. One way the federal government can reduce risk is by providing substantial cost-share, such as 50 percent of the costs, and workable loan guarantee programs to help finance the first ten commercial projects. Currently, the USDA development grant and loan programs that would potentially benefit electric cooperatives and other rural communities home to electric power stations will only lend to projects utilizing proven technologies, and therefore will not lend to CCS projects. This needs to be fixed so that CCS technology can either qualify for development grants and loan guarantees or CCS technology needs to be brought to mainstream acceptance so these programs can be utilized for CCS projects. The same could be said for commercial lenders.

Congress also needs to look at how companies can build the costs of new technologies into their rate bases. While many of those issues are handled at state level pubic service commissions, the Regional Transmission Organizations (RTO's) are governed by FERC and Congress should explore what can be done at a federal level to encourage technology adoption.

Utility scale projects and the technology development timelines can be well over a decade, which exceeds an entire presidency. Congress needs to show long-term and continued support for these programs. Eliminating a program at eight years would be pulling the rug out from underneath developers, setting the course back years. Presidential administrations will all have different priorities, but dedicated funding with vocal support would be a strong signal from Congress to technology developers, and utilities and investment communities which will ultimately make commercial scale investment decisions. It is imperative that Congress closely monitors actions at the Department of Energy to ensure congressionally authorized offices and programs are funded and staffed as mandated. We are concerned hearing that experience carbon capture technology experts are being transferred from the Office of Fossil Energy and the administration may be undermining the effectiveness of that office. Moving technical experts or leaving positions unfilled will have ripple effects across programs.

Congress also needs to look at the entire scope of a commercial project. Adequate support for technology is only one piece of the equation. Long-term liability for CO2 storage is an unresolved question. It is difficult to envision a project receiving financing or insurance if they had a liability into perpetuity. Congress should look at assuming the long-term liability of geologic sequestration sites at a point where experts have determined the site to be stable after the cessation of injection activities.

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April 22, 2021 Hearing: ***Opportunities and Challenges that Exist for Advancing and Deploying Carbon and Carbon-Dioxide (CO2) Utilization Technologies in the United States***
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In the west and states like Wyoming that have large portions of federal lands, federal permitting reform is something that is necessary. In Wyoming, there is a company seeking to construct a major wind farm with a dedicated transmission line to deliver power to the Southwestern states. They applied for their first permits in 2006 and have yet to receive everything they need. That project is now working with their fourth presidential administration. The Bureau of Land Management (BLM), US Fish Wildlife Service, US Forest Service (USFS) along with an array of state and local permitting entities have made the development of multijurisdictional projects almost impossible. The developers of the reference project state they have spent over $100 million on permitting alone and multiple projects of this size would be needed to achieve the Administration's CO2 reduction goals. One can only image the regulatory challenges of permitting and building a major CO2 pipeline across the western U.S.

NEPA will likely have impacts beyond project construction. The law requires all federal agencies to perform environmental assessments to identify the environmental impacts of their actions. It is not unreasonable to think that a NEPA response would be triggered if the USFS or BLM set aside certain lands for terrestrial sequestration. The courts have ruled that an administration cannot ignore NEPA requirements.

In Indigenous Environmental Network v. United States Department of State a US District Court ruled, "No agency possesses discretion whether to comply with procedural requirements such as NEPA. The relevant information provided by a NEPA analysis needs to be available to the public and the people who play a role in the decision-making process. This process includes the President."

As mentioned, the permitting timeline can take well over a decade and even the best-intentioned programs are not exempt from the NEPA process.

2) How can the wide-scale deployment of these technologies revitalize coal communities across the country?
Wyoming's coal producing areas are home to an array of technical skill sets. Today's coal miners utilize a wide range of computer programs, GPS software and maintenance programs to do their jobs safely and as efficiently as possible. These are increasingly technical jobs with employees that have a wide range of abilities. In fact, NASA's space shuttle transporter was overhauled by a company based in Gillette Wyoming known for their work on mining equipment. The question of how to transfer these employees to new careers as mines contract does not have an easy answer. Some have made the decision on their own to enroll in educational programs to learn a new career. Others love operating heavy equipment, working outdoors or having a work schedule which allows them blocks of time to work on their family ranches or enjoy the outdoors.

The idea that coal miners can learn to code or completely transition to another skill is largely scoffed at in coal communities. These are their homes and communities in which they have raised their families and lived in for a long time. They do not want to move away. They want careers that they enjoy and find fulfilling, living in a place they love. Not all employment is equal. Coal mining provides a career where they travel to the same place every day, affording the opportunity to be home with their families at the

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April 22, 2021 Hearing: *Opportunities and Challenges that Exist for Advancing and Deploying Carbon and Carbon-Dioxide (CO2) Utilization Technologies in the United States*
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end of each shift. A senior operator at one of the mines can earn more than $100,000 per year. Jobs in renewable energy construction are much more transient, requiring workers to be on the road, traveling from project to project as most of the work is completed during the construction phase. The Bureau of Labor Statistics states the median salary for a wind technician to be $56,000 per year. That is not a bad salary, but it is half of what some coal miners earn.

New carbon management technologies can have a great impact in these communities in several ways. Certain powerplants may be able to operate longer, which would ensure coal mining jobs. For example, there is a powerplant in Wyoming that is projected to operate for another 50 years. It consumes about 4 million tons of coal per year and if it operates for its projected lifespan, it will need 200 million tons of coal, which is about Wyoming's total annual output. If several plants were to utilize post-combustion carbon capture systems, it would keep a lot of people employed. We need to remember it is not only the direct coal mining jobs. Equipment dealers, mechanics, fuel delivery drivers, engineering firms, parts suppliers and custodial crews are just a sample of people directly impacted by coal jobs. People do not want jobs; they want careers and coal mining has been a great career for many people.

Another opportunity is in the development of technologies itself. West Virginia certainly has seen economic impacts and new jobs due to NETL and the base of knowledge that facility has attracts other opportunities. The Wyoming ITC seeks to do the same and we are hopeful the one-of-a-kind facility can attract similar talent and opportunities. With excellent geology for CO2 storage and EOR, favorable politics, community support, an existing CO2 pipeline network and a state with permitting primacy, we think Wyoming's coal communities can make a compelling value proposition for why carbon management projects should be constructed there. Many of the skills outlined above would be transferrable to these new or evolved industries.

The energy economy is changing, and nobody questions that. However, can we learn from the past and ensure the employees who powered America are not abandoned during this transition. A top-down approach from someone living several states away is generally not going to be well received at the grassroots level. Working hand in hand with these communities, taking stock of the strengths of the area and workers, and collaboratively understanding the opportunities will achieve the best outcomes.

U.S. Senate Committee on Energy and Natural Resources

April 22, 2021 Hearing: ***Opportunities and Challenges that Exist for Advancing and Deploying Carbon and Carbon-Dioxide (CO_2) Utilization Technologies in the United States***

Questions for the Record Submitted to Prof. Gaurav N. Sant by Chairman Joe Manchin III

The President set an ambitious goal of a 50% emissions reduction by 2030 which includes the use of CCUS. As discussed in the hearing, meeting this target will require a developed, thriving CCUS ecosystem from capture to end-use, which includes wide-scale deployment of carbon utilization technologies.

1) **Can you expand on your comments on what specifically is needed to commercialize and widely deploy carbon capture, utilization and storage technologies to help meet this ambitious target?**

Technologies for the capture, utilization, and storage of carbon dioxide ("CCUS") are unquestionably the most significant pathway to help meet the U.S.'s emissions reductions targets. While we have invested considerable efforts, intellectual, financial, and otherwise over the past decades, few if any carbon management technologies have achieved commercial scale and viability. And, as things stand, there are only a few technologies, which if any, could be brought to a sufficient scale of technological maturity to be implemented, economy wide, in the next five-to-ten years or so.

Of note, since the majority of carbon dioxide (CO_2) emissions originate from mundane industries and operations that we often take for granted, but that most affect our lives (e.g., liquid fuels, electricity production, steel, cement and concrete production, etc.) it is particularly important to derisk and scale carbon management technologies to demonstrate their effectiveness and to assure the private sector of the technical and economic viability and scalability of new technologies. This is crucial as otherwise the private sector has little ability (or interest) to deploy unproven technologies at scale due to uncertainty in revenue, and profit, substantial regulatory and compliance burdens, and the very high costs associated with emplacing greenfield facilities with long operating horizons.

To answer the primary question in brief: Is the President's 50% emissions reduction target achievable? In short, absolutely yes, but what is needed is as follows. The U.S. needs to mobilize a national endeavor and make a focused commitment not only to develop and allocate funding to expand the scientific and intellectual underpinnings of carbon management technologies, but also to: 1) build out and greatly expand support for large technology derisking and demonstration programs including the construction of commercial-scale first-of-a-kind (FOAK) facilities, 2) simplify, streamline and expedite regulatory and permitting processes for the deployment of CCUS technologies; both during the demonstration (FOAK) and commercial deployment phases, and 3) emplace adjacent infrastructure and infrastructure systems which are required for ensuring carbon management. Beyond these activities, it is also foundationally necessary to: 4) create markets for low-carbon products and services; e.g., by the speedy implementation of a federal buy clean program which is based on state-of-the-art, up-to-date and unimpeachable data maintained in federal repositories related to the lifecycle carbon impacts of goods and services of which the federal government is a buyer, and 5) to create incentive structures (e.g., based on direct payments, tax credits, etc.) that are transparent, easily accessible and are attractive to both early-stage companies, and established corporations.

While these are substantive needs, they cannot be fulfilled piecemeal, and selectively. These actions need to be implemented comprehensively, together and in a timely manner. Why? Carbon management and emissions reduction at the scales of relevance is a formidable challenge like no other. In effect, it implies diminishing our (the U.S.'s) per capita carbon dioxide (CO_2) footprint from +20 tons per person per year [2021] to -10 tons per person per year from 2050 until the end of the century. Achieving this goal requires decisive action on behalf of Congress to spur a national call to action, and to catalyze societal, commercial, and industrial transformations. This requires 360° of situational (market, technology, and policy) focus and action by the federal government that is implemented in a prompt manner, i.e., the next 12-18 months or less.

2) How can the wide-scale deployment of these technologies revitalize coal communities across the country?

The U.S. green economy which is based not only around CCUS technologies and its products, but also the creation of low(er) carbon trajectories based on industrial efficiency improvements in existing industries is estimated to employ, in time, well over 10 million workers. Unquestionably, the ongoing energy transition will disproportionately affect (and is affecting) coal communities which for generations have provided a critical and essential source of energy for the development of our nation.

The revitalization of these communities requires systematic action including: a) the creation of new manufacturing enterprises based in coal communities that will enable the rebuilding of U.S. infrastructure with low-carbon construction materials (e.g., low-carbon concrete), b) federal support for retrofitting and installation of CCUS technologies on existing power and industrial plants to prevent plant shutdowns or existing manufacturing outsourcing, c) the creation of new supply chains, and processing facilities for critical materials in coal communities not only for reasons of national security, but also to emplace the U.S. as a critical materials supplier for the world [N.B.: abundant access to critical materials is required to ensure the global clean energy transition], d) job retraining programs to engage workers from coal communities in new employment opportunities beyond mining and (coal) power generation, and e) greatly enhanced research, development, and commercialization support for the creation of new technological pathways and manufacturing facilities to transform coal- and coal-based residues into materials ranging from carbon fiber to carbon black, and the development of industries and applications wherein these materials will find widespread usage. Once again, it is necessary that these supportive actions be implemented simultaneously and comprehensively, so that coal communities are revitalized and prosper, starting now, and in the times to come.

U.S. Senate Committee on Energy and Natural Resources
April 22, 2021 Hearing: ***Opportunities and Challenges that Exist for Advancing and Deploying Carbon and Carbon-Dioxide (CO2) Utilization Technologies in the United States***
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Questions from Chairman Joe Manchin III

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1) Can you expand on your comments on what specifically is needed to commercialize and widely deploy carbon capture, utilization and storage technologies to help meet this ambitious target?

   Comment:
   If the US is to meet as ambitious goal as proposed, the Federal Government needs to approach this with a "Manhattan Project" like focus, funding and dedication. As I noted in my testimony, China is already dramatically ahead of the US in the technology, infrastructure and amount of coal resources being dedicated to "coal to products" as opposed to combustion/emissions.

   I would like to propose:
   - Dramatically higher funding toward R&D associated with the development of new uses for "newly mined" coal to create new forms of advanced carbon products and materials. There is currently a bias held by the political appointees at the Department of Energy against any encouragement or research funding for projects involving newly mined coal, as opposed to the use of coal waste.
   - Create an Office within the Department of Energy which is specifically tasked with the Development of Carbon Utilization (as opposed to the Office of Fossil Energy). This office would be tasked to fund and cultivate new technologies involving coal to products using every form of the available carbon ore resource.
   - Expand the 45Q tax provisions to include specifically newly mined coal to products. Also include tax provisions which would provide an equal dollar tax credit for removal of greenhouse gases, as opposed to simply a tax on their emission.
   - Specifically provide for appropriation for $50 million for coal to product pilot facilities on both the Eastern and Western coal basins. Ramaco Carbon will have the prototype for this facility opening this summer outside of Sheridan, Wyoming. It would propose to build and develop a complementary facility in West Virginia near one of Ramaco's active metallurgical coal complexes.

2) How can the wide-scale deployment of these technologies revitalize coal communities across the country?

   I would like to propose:
   - The creation of a national program of "Carbon Camps" which would stand for "Carbon Advanced Material and Product" centers.

U.S. Senate Committee on Energy and Natural Resources
April 22, 2021 Hearing: ***Opportunities and Challenges that Exist for Advancing and Deploying Carbon and Carbon-Dioxide (CO2) Utilization Technologies in the United States***
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- Locate CAMP centers in coal-producing areas where mine-mouth logistical advantages and access to smart, skilled coal mining talent can be accentuated.
- We "repurpose" older mining communities into advanced manufacturing hubs.
- Focus on the manufacture of environmental advanced carbon products and materials with high value margins, *and* which require the use of newly mined coal as the basic carbon feedstock.
- **Build an innovative, higher tech future for the coal industry** independent of power trends and environmental concerns.
- With Federal and State support, construction could start almost immediately.
- The Federal Government can fund a public/private pilot center and pre-commercial facilities per Coal Tecc legislation already passed.
- We plan to invest in center in coal states with our existing production like West Virginia, Wyoming, Pennsylvania, Virginia, Kentucky, and more.
- Creating CAMP centers near mines creates synergies with huge logistical cost advantages by avoiding transportation of bulk feedstocks for manufacturing.
- Even non-coal coastal states have significant economic and political interests in advanced carbon materials and life sciences.

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Submission for the Record

Full Committee Hearing On Carbon Utilization Technologies

Hearing of the US Senate Committee on Energy and Natural Resources

April 22, 2021

The Value of Advanced Energy Funding: Projected Effects of Proposed US Funding for Advanced Energy Technologies

Expert analysis and RFF modeling show that authorizing funding for key technologies under the Energy Act of 2020 would create significant societal benefits from 2040-2060. Combined with a clean energy standard, a majority of these benefits would come from lower consumer electric bills.

Issue Brief (21-03) by Daniel Shawhan, Kathryne Cleary, Christoph Funke, and Steven Witkin

This issue brief was published by Resources for the Future (RFF) in April. To view the final, published version, please click here.

Key Takeaways

The benefits of additional research, development, and demonstration (RD&D) for advanced energy technologies are likely to greatly exceed the costs. Additional funding like that authorized by the Energy Act of 2020 would generate projected societal benefits averaging $30 billion to $40 billion in present value per technology during 2040–2060.[1]

Twenty-six experts in advanced nuclear, advanced geothermal, energy storage, natural gas with carbon capture and sequestration (NG-CCS), and direct air capture (DAC) projected the effects of the additional RD&D funding on the future costs of the technologies. The experts expect the additional funding to reduce the costs of the technologies by 9–30 percent in 2035, compared with the case of no additional funding.

Average power sector benefits across the technologies are likely to exceed costs by about 7 times if there is no new national clean energy policy and by more than 10 times if there is a national clean energy standard (CES). Benefits outside the power sector may also be significant and would increase these ratios. An economy-wide analysis for DAC found benefits of 27 times the costs of the additional funding, assuming a national economy-wide emissions policy.

Without a CES, the estimated benefits of added RD&D funding are split mainly among lower electricity bills, health benefits, and climate benefits. With a CES, the estimated benefits are mainly in the form of lower electricity bills. Average annual electricity bill savings per household for each technology are about $14 without a CES and $56 with a CES.

Context

In December 2020, President Trump signed the Energy Act of 2020 into law, authorizing significant federal funding for the research, development, and demonstration (RD&D) of advanced clean energy technologies. The act earmarked additional funding for each of the technologies addressed in this study.

As of this writing, Congress has not acted to appropriate funds under the Energy Act of 2020. It is uncertain how much funding each of these technologies will receive. They could receive less than authorized in the act, or more, perhaps as part of stimulus, infrastructure, or energy legislation.

This issue brief summarizes the findings of a new study that estimates some of the effects of proposed additional spending for these five advanced, clean energy technologies,[2] building on two 2020 RFF simulation-based studies. This issue brief illustrates how investing in RD&D can help make these technologies cost-competitive and, by extension, drive down the cost of energy, whether new national clean energy requirements are adopted or not.

Although this research began before the Energy Act of 2020 was passed, the programs and funding analyzed here closely align with what the act authorized.

Summary of Study

This study brings together results from two sources: technology cost projections from 26 technology cost experts, and simulations from past studies that calculate societal benefits of cost reductions for the technologies. The analysis estimates the benefit-to-cost ratio of additional funding for each technology in two scenarios: one that includes a national clean electricity standard (CES) that requires 94 percent of power to be generated from clean sources by 2050, and another that assumes status quo domestic climate policy without a national CES. For direct air capture technology (DAC), an additional third scenario—achieving cost-effective economy-wide emissions at approximately 50 percent below 2005 levels by 2050—is used to estimate the economy-wide benefits of the technology.

To assess future technology costs, the experts provided estimates for average lifetime costs of the technology they study in 2035, both with and without 10-year additional funding streams similar to those authorized under the Energy Act of 2020. The experts also estimated the increase in public and private RD&D spending from 2022 to 2031 that would result from such funding.

Societal benefits of additional funding were estimated by mapping the experts' cost predictions onto simulation results in Shawhan, Funke, and Witkin (2020), which models power-sector effects of all five technologies, and in Hafstead (2020), which models economy-wide effects of DAC. This study uses the simulations to estimate annual power sector benefits in 2050 and assumes that they are representative of the annual benefits from 2040 to 2060.

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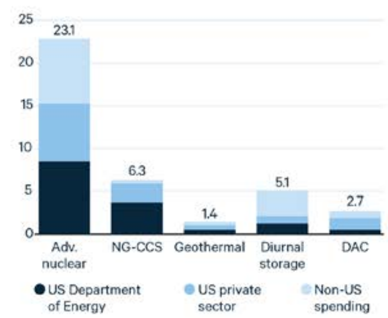
Notably, several categories of benefits are not included here: benefits outside the electricity sector (except for DAC), benefits outside the years 2040–2060, US export profits, benefits from reduced foreign emissions, or benefits from the use of the advanced energy technologies outside the United States. Including these would likely increase the benefits of this funding. Also, the benefits are modeled under the conservative assumption that cost projections for 2035 would still apply in 2050. In reality, costs tend to decline over time, especially with use, and our detailed results in the full report show that as the cost reductions grow larger, the central benefit estimates grow much larger.

Findings

Effects of Funding on Public and Private RD&D Spending

For all technologies studied, the experts estimate that additional RD&D funding by the US government (dark blue in Figure 1) will also increase US private RD&D spending (light blue) and foreign RD&D spending (lightest blue).

Figure 1. Projected Effect of Legislation on RD&D Spending if Fully Funded for 10 Years, FY2022– FY2031 (billions of undiscounted 2020$)



Effects of Funding on Future Technology Costs

Experts' responses show that 10-year RD&D funding (like that authorized by the Energy Act of 2020) could reduce the costs of each of the five analyzed technologies by 9–29 percent in 2035.

Figure 2. Estimated Average Cost Reductions in 2035 Due to 10-Year RD&D Funding

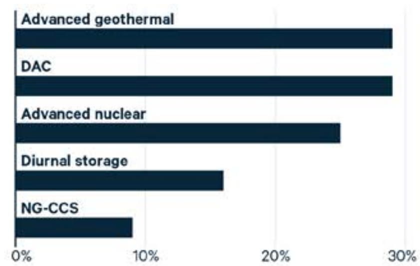
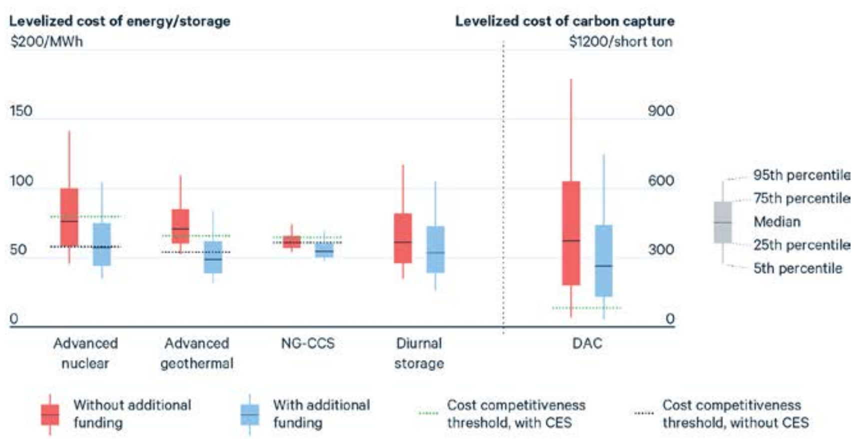


Figure 2 shows the average cost reductions expected for each technology. Figure 3 shows the same cost reductions plus the uncertainty about each one.

Figure 3 also shows cost-competitiveness thresholds calculated in Shawhan, Funke, and Witkin (2020). Cost-competitiveness is defined here as the cost needed for a technology to account for 1 percent of power generation.

Figure 3. Uncertainty Ranges for Levelized Cost, With and Without Added RD&D Funding



Figures 2 and 3 provide a few key takeaways:

Experts expect the additional RD&D funding to reduce levelized costs of these technologies across the board, though by different amounts for different technologies.

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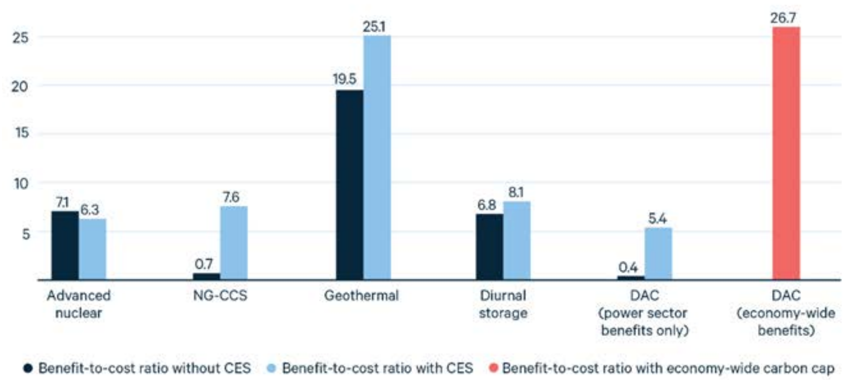
The dashed lines, showing cost-competitiveness thresholds with and without a national CES, provide context for these estimates of cost reductions. Across all five technologies, legislation increases the likelihood of future cost-competitiveness with other, more traditional technologies, by 20 percentage points on average.

None of the technologies are certain to be cost-competitive, which is a reason to fund RD&D for multiple technologies.

Benefits of Additional RD&D Funding

Additional funding for advanced energy technologies is likely to bring down the costs of the technologies, but what effect will these reduced costs have on society? Based on the results above and in previous simulations, the additional funding would generate estimated average societal benefits of $30 billion per technology without any new national clean energy policy, assuming a 20-year benefit stream. With a CES requiring that 94 percent of electricity generation come from clean energy sources, the average societal benefits over 20 years jump to an average of $39 billion per technology. Both of these are present values discounted at 3 percent annually. All dollar values in this brief are in 2020 dollars.

Figure 4. Estimated Benefit-to-Cost Ratios from 10 Years of RD&D Funding



Both with and without a CES, the benefits of the additional funding are, on average, several times as large as the costs. An estimated benefit-to-cost ratio—the benefits of funding per dollar of costs—is presented for each technology in Figure 4. In the figure, all benefit-cost ratios include only benefits from the technology's power sector use, except those in the right-most column for DAC. Among the five analyzed technologies, average estimated benefits in the power sector are 6.9 times greater than costs in the case without a CES, and 10.5 times the costs in the case with one. All of the benefit estimates in this study are central estimates for the types of benefits included in the study; the true benefits could be considerably higher or lower.

Without a CES, the estimated benefits of added RD&D funding are split mainly among lower electricity bills, health benefits, and climate benefits. With a CES, the estimated benefits are mainly in the form of lower electricity bills. Electricity bill savings amount to an average of approximately $14 per household per year for each technology without a CES and $56 per household per year for each technology with a CES.

Conclusions

Experts believe that increased US federal funding will reduce the costs of these five advanced energy technologies, partly through spillover effects on private and international RD&D spending.

Under a national CES, the estimated benefits of additional funding are more than four times the costs for all five technologies for which benefits are calculated. Without any new national clean energy policy, this is true for three of the five technologies.

Ten years of federal RD&D funding at the levels authorized in the Energy Act of 2020 would create an estimated $30 billion to $40 billion in future societal benefits per technology, with a substantial amount directed back to electricity users in the form of reduced electricity costs.

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