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BEFORE THE

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ON

CARBON UTILIZATION

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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.