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Carbon Capture and Storage

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Thank you Chairman Murphy, Ranking Member DeGette, and members of the Subcommittee. I appreciate the opportunity to discuss the Department of Energy's (DOE) coal research and development (R&D) activities, including carbon capture and storage (CCS).

Coal fuels approximately 40 percent of our domestic electricity production. As the Energy Information Administration (EIA) recently pointed out in the Annual Energy Outlook 2014 reference case, coal will continue to be one of the two most important sources of electricity generation through 2040. Because it is abundant, the clean and efficient use of coal is a key part of President Obama's all-of-the-above energy strategy.

A major challenge to coal, however, is that it is a major source of carbon dioxide (CO_2) emissions. Therefore, it is critical that we promote currently available technologies and develop more economic and broadly available technologies to reduce those emissions from coal-fired power plants. To that end, the Obama Administration strongly supports the development of clean coal technologies, including carbon capture and storage, as a critical component to an energy-rich, environmentally sound energy economy. In addition to the Administration's annual budget requests, that support was made clear in the 2009 American Recovery and Reinvestment Act (Recovery Act), which provided $3.4 billion for CCS. This followed over 15 years of

appropriations that have provided the science and technology foundation for CCS deployment in the US and around the world. It was also evident in the formation of the Interagency Task Force on Carbon Capture and Storage, which the President charged in February 2010 to develop a plan to overcome the barriers to the widespread, cost-effective deployment of CCS within 10 years.

On June 25, 2013, President Obama laid out a broad Climate Action Plan to cut carbon pollution in America, prepare the United States for the impacts of climate change, and lead international efforts to combat global climate change. A key component of that plan is an $8 billion loan guarantee solicitation, which was released on December 13, 2013. The solicitation covers a broad range of advanced fossil energy projects, and is designed to support investments in innovative technologies that can cost-effectively meet financial and policy goals, including the avoidance, reduction, or sequestration of anthropogenic emissions of greenhouse gases.

As the President has made clear, fossil fuels – including coal – provide more than 80 percent of our energy today and they are projected to remain a large source of energy for decades. The fossil solicitation – in addition to the $6 billion the Administration has already committed to clean coal technologies – reflects the Administration's commitment to an "all of above" energy strategy that develops every available source of American energy – a strategy that's cleaner, cheaper, and full of new jobs.

Clean Coal Research Program

DOE continues to play a leadership role in the development of clean coal technologies with a focus on CCS. The Clean Coal Research Program – administered by DOE's Office of Fossil Energy and implemented by the National Energy Technology Laboratory (NETL) – is designed to enhance our energy security and reduce environmental concerns over the future use of coal by developing a

portfolio of cutting-edge clean coal technologies. The Program is well positioned to help overcome the technical challenges associated with the development of clean coal technologies.

The Clean Coal Research Program, in partnership with the private sector, is focused on maximizing efficiency and environmental performance, while minimizing the costs of these new technologies. In recent years, the Program has been restructured to focus on clean coal technologies with CCS. The Program pursues the following two major strategies:

1) capturing and storing greenhouse gases; and

2) improving the efficiency and footprint of fossil energy systems.

The first strategy aims to remove emissions of greenhouse gases from fossil fueled energy systems. The second strategy seeks to improve the fuel-to-energy efficiencies of these systems, thus reducing pollutant emissions, water usage, and carbon emissions on a per unit of energy basis. Collectively, these two strategies constitute the Clean Coal Research Program's approach to ensure that current and future fossil energy plants can contribute to a safe and secure clean energy future.

Core Research and Development Activities

The Clean Coal Research Program is addressing the key challenges that confront the development and deployment of clean coal technologies through research on cost-effective capture technologies; monitoring, verification, and accounting technologies to ensure permanent storage; and development of advanced energy systems. Research is focused on developing technology options that dramatically lower the cost of capturing carbon dioxide from fossil fueled energy plants. This research can be categorized into three technical pathways: post-combustion, pre-combustion, and oxy- combustion. Post-combustion refers to capturing CO_2 from the stack gas after a fuel has been

combusted in air. Pre-combustion refers to a process where a hydrocarbon fuel is converted to a mixture of hydrogen and carbon dioxide, and CO_2 is captured from the gas mixture before it is combusted. Oxy-combustion is an approach where a hydrocarbon fuel is combusted in pure or nearly pure oxygen rather than air, which releases energy and produces a mixture of CO_2 and water that can easily be separated to produce pure CO_2. We pursue all three pathways today because all three pathways are comparable in terms of cost and efficiency, and all have engineering strengths.

Collectively, research in each of these technical pathways is exploring a wide range of technical approaches such as hydrogen membranes; oxy-combustion concepts; solid sorbents; catalyzed solvents; advanced gas/liquid scrubbing technologies; and advanced hybrid concepts such as liquid membrane contactors.

These efforts cover not only improvements to state-of-the-art technologies but also development of several revolutionary concepts, such as metal organic frameworks, ionic liquids, enzyme-based systems, and chemical looping – a form of oxy-combustion that utilizes oxygen from metal oxide as an oxygen carrier for fuel combustion, or for making hydrogen by "reducing" water. In combustion applications, the products of chemical looping are CO_2 and H_2O as steam. Thus, once the steam is condensed, a relatively pure stream of CO_2 is produced ready for sequestration. This work has also led to manufacturing breakthroughs in microfluidics, nanofabrication, and molecular design. Coupling these developments with other advances in efficiency improvements and cost reduction from developments in gasification and turbines will help provide a technology base of fossil energy systems integrated with CCS that will be widely adopted.

Regional Carbon Sequestration Partnerships

The Regional Carbon Sequestration Partnerships were created by DOE in 2003 through a

competitive solicitation. The Partnerships were designed to address a range of issues associated with geologic storage of CO_2. The Clean Coal Research Program has been performing CCS field tests focused on injection, monitoring, verification, accounting and other aspects of geologic storage for many years, and the seven Regional Carbon Sequestration Partnerships are critical to this effort. These Partnerships are comprised of state agencies, universities, and private companies. They represent more than 400 unique organizations in 43 States, and four Canadian Provinces. Geographic differences in fossil fuel use and potential storage sites across the United States dictate the use of regional approaches in addressing CCS, so each Partnership is focused on a specific region of the United States and Canada that holds similar characteristics relating to CCS opportunities.

Together, the Partnerships form a network of capability, knowledge, and infrastructure that will help enable geologic storage technology to play a role in the clean energy economy. They represent regions encompassing 97 percent of coal-fired CO_2 emissions, 97 percent of industrial CO_2 emissions, 96 percent of the total land mass, and essentially all the geologic storage sites that can potentially be available for geologic carbon storage.

During the Validation Phase of the program, Regional Partnerships drilled wells and injected small quantities of CO_2 to validate the potential of key storage locations totaling more than 1 million metric tons of CO_2 at 19 small scale injection projects throughout the United States and Canada. Those tests helped to validate storage at a small scale to understand the fate of CO_2 in different depositional systems containing saline water, oil, and natural gas, and helped test and strengthen simulation and monitoring tools and approaches required for commercialization. The program is currently in the Development Phase, during which large-scale field testing involving at least 1 million metric tons of CO_2 per project will be injected. Tests are designed to not only investigate

commercial-scale injection of CO_2, but will also be used to understand the necessary regulatory, economic, liability, ownership, and public outreach efforts needed for successful CCS, and to develop the necessary human capital, knowledge base, and experience necessary to implement future CCS operations. Several of the large-scale tests are currently underway and one project has safely injected over 3.6 million metric tons and is being monitored for safe and permanent storage.

Over the course of these initiatives, DOE and the Partnerships are addressing key infrastructure issues related to permitting, pore space ownership, site access, liability, public outreach, and education. An important product of this work is a series of Best Practice Manuals on topics such as site characterization, site construction, operations, monitoring, mitigation, closure, and long-term stewardship. These Manuals will serve as guidelines for a future geologic sequestration industry in their regions, and help transfer the lessons learned from DOE's Clean Coal Research Program to all regional stakeholders. The first editions of the Best Practice Manuals are available on DOE's reference shelf [1] and the Manuals will be periodically updated as lessons learned from the large scale field tests are realized.

We have also pursued projects designed to develop technologies and protocols for the monitoring, verification, and accounting (MVA) of CO_2 storage in geologic formations as well as simulating the behavior of geologically-stored CO_2. MVA of geologic storage sites is an important part of making geologic storage a safe, effective and reliable method of greenhouse gas control. These activities will culminate in a set of best practices for the deployment of carbon capture, utilization and storage technology.

In addition to this foundational science, technology, infrastructure, and practice, DOE and the Partnerships continue to work closely with the Environmental Protection Agency (EPA) and

[1] http://www.netl.doe.gov/research/coal/carbon-storage/carbon-storage-infrastructure/best-practices

other Federal and state agencies in developing CCS regulatory strategies, which will provide additional certainty for future CCS deployments.

Demonstrations at Commercial-Scale

The Clean Coal Program's work is to meet the technical and economic challenges associated with the deployment of newer coal technologies. Commercial-scale demonstrations help the industry understand and overcome start-up issues, address component integration issues, and gain the early learning commercial experience necessary to reduce technology risk and secure private financing and investment for future plants.

The Department is implementing commercial-scale demonstration projects through the Clean Coal Power Initiative (CCPI), FutureGen 2.0, and the Industrial Carbon Capture and Storage (ICCS) programs. These projects together cover a wide range of important technologies, settings and potential applications. These include pre-, post-, and oxycombustion projects; new builds and retrofits; saline formation storage and enhanced oil recovery; siliciclastic and carbonate reservoirs; coal and petcoke conversion; power sector and industrial sector applications; and the geographic diversity that represents regulatory and economic diversity nationwide. The portfolio of projects is designed not only for technical and commercial success, but also to maximize learning and value to the public.

The CCPI is a cost-shared partnership between the Government and industry to develop and demonstrate advanced coal-based power generation technologies at the commercial scale. By enabling advanced technologies to overcome technical risks involved with scale-up and bringing them to the point of commercial readiness, CCPI accelerates the development of advanced coal generation technologies integrated with CCS. The CCPI also facilitates the movement of

technologies into the marketplace that are emerging from the core research and development activities.

The CCPI program received an additional $800 million from the Recovery Act which, in combination with base funding, was used to fund four CCPI Round III projects, of which two pre-combustion (new builds) and one post-combustion capture (retrofit) projects are still active. In addition, a CCPI Round II project, with Southern Company Services, was modified to demonstrate CCS at a new integrated gasification combined cycle power plant. Having completed all design, planning, and environmental review requirements, this project began construction in 2010 and project construction is now more than 75 percent complete.

The FutureGen 2.0 Project intends to conduct novel large-scale testing to accelerate the deployment of advanced oxy-combustion power production technologies integrated with CCS. This project will be the first advanced repowering oxy-combustion project to store CO_2 in a deep saline geologic formation. On August 5, 2010, then-Secretary of Energy Steven Chu announced an award totaling $1 billion in Recovery Act funding to 1) The FutureGen Alliance and 2) Ameren Energy Resources along with their partners (Babcock & Wilcox and Air Liquide Process and Construction, Inc.) to repower an existing plant with advanced oxy-combustion technologies. Together, these two awards comprised the FutureGen 2.0 project for clean coal repowering with CCS. On February 28, 2011, the FutureGen Alliance selected Morgan County, Illinois, as the preferred location for the FutureGen 2.0 CO_2 storage site, visitor center, and research and training facilities. The Alliance has subsequently taken over leadership of both projects comprising the FutureGen 2.0 program.

FutureGen 2.0 successfully completed Phase I, which included identification of a sequestration site, preliminary characterization and test drilling, and a commitment from the Illinois Commerce

Commission to cover the project's output under its purchasing plans. Phase II commenced on February 1, 2013. Last month, DOE issued a Record of Decision to provide financial assistance to the FutureGen Alliance for the project. The Department intends to provide approximately $1 billion of financial assistance for the project (the majority of which is authorized under the ARRA through cooperative agreements with the Alliance).

In addition to the CCPI and FutureGen 2.0 projects, the Recovery Act has also helped fund more than 80 additional projects, which includes three large scale ICCS demonstrations, 10 geologic site characterizations, 43 university research training projects, seven CCS research training centers, six ICCS projects focused on CO_2 reuse, and 14 projects focused on accelerated component development in the core research program.[2]

Examples of progress on these projects include the Archer Daniels Midland ICCS project in Illinois, which will demonstrate an integrated system of CO_2 capture in an ethanol production plant and geologic sequestration in a sandstone reservoir. This project is under construction and approximately 49 percent complete. In Texas, the Air Products and Chemicals, Inc. ICCS project recently began capturing CO_2 from two steam methane reformer hydrogen production plants for enhanced oil recovery (EOR) operations. This project is the first to capture CO_2 at large scale from steam methane reformers used for hydrogen production, with the captured CO_2 then utilized for EOR. In December 2013, the Department issued a Record of Decision on the Leucadia ICCS project in Louisiana, completing the environmental compliance process. When operational, this project will sequester 4.5 million metric tonnes per year of CO_2 for EOR.

[2] Details about all of the Fossil Energy projects funded by the Recovery Act can be found here: http://energy.gov/fe/fe-implementation-recovery-act.

It is important to understand that every large demonstration project matures through a series of stages, each of which requires important milestones and results. These allows the teams of managers at DOE headquarters and NETL to monitor progress, manage changing national and global commercial settings, and ensure appropriate use of public funds in support of the approved national objectives.

CO_2 Utilization Technologies

The coal research and development program has supported research on CO_2 utilization technologies for more than a decade. When the Carbon Storage Program (formerly named the Sequestration Program) was initiated in the mid-1990s, it was recognized that technologies such as mineralization, chemical conversion to useful products, algae production, enhanced oil recovery and enhanced coal bed methane recovery could play an important role in mitigating CO_2 emissions. Other than EOR, the CO_2 emissions reduction potential of these approaches is limited, due to factors such as cost and market saturation of salable byproducts. Even so, these approaches are logical "first-market entry" candidates for greenhouse gas mitigation, due to their ability to produce revenue from use of the CO_2 that could be used to offset the costs for these "early adopters." Hence, these options provide a technology bridge and smoother transition to the deployment of the large-scale, stand-alone geologic sequestration operations that will ultimately be needed to achieve the much larger emissions reductions required to approach stabilizing greenhouse gas concentrations in the atmosphere.

EOR represents the most near term and most commercially attractive utilization option for captured CO_2. Over the history of the Department, the focus of CO_2-EOR R&D has shifted from increased incremental oil production to monitoring, verification, and accounting of geologically stored CO_2

as part of a climate change mitigation strategy. As early as the 1970s, DOE-funded projects were developing concepts to improve the effectiveness and applicability of CO_2-EOR. Currently, most commercial EOR projects have been strategically located near cheap sources of naturally occurring CO_2 or along pipelines from such sources. If research into reducing the cost of CO_2 capture from power plants proves successful, anthropogenic sources of CO_2 may become readily available for EOR projects.

The DOE's 2012 Carbon Utilization and Storage Atlas of the United States projects a potential CO_2 storage resource estimate of over 200 billion tonnes for oil and gas reservoirs in the United States. In the near-term, incremental oil produced via EOR using anthropogenic CO_2 could help offset the costs of CO_2 capture. The prospect of relatively low-cost supplies of captured CO_2 in widespread areas of the country could, in turn, provide the impetus for a national re-evaluation of the EOR potential in many mature fields. While conventional EOR is a widely-used process, CO_2 capture and permanent storage is not yet widely used at power plants. Continued evolution of EOR and transformational advances in development and deployment of CO_2 capture from coal power could help realize the synergy between the coal/power industry and the oil industry. Utilization of the CO_2 in EOR will impart knowledge that will be instrumental in the Department's continued focus on R&D in other geologic storage formations such as saline that have a larger storage potential for CO_2.

Conclusion

Today, nearly three out of every four coal-burning power plants in this country are equipped with technologies that can trace their roots back to DOE's advanced coal technology program. These efforts helped accelerate production of cost-effective compliance options to address legacy

environmental issues associated with coal use. CCS and related clean coal technologies can play a critical role in mitigating CO_2 emissions under many potential future carbon stabilization scenarios. CO_2 utilization technologies with salable byproducts are logical "first market entry" candidates for greenhouse gas mitigation due to their ability to produce revenue from the use of CO_2. EOR will be the dominant utilization opportunity in the near term and will impart additional experience that will be useful in the Department's continued focus on R&D in other storage formations, such as deep saline aquifers, necessary to address climate change. Nevertheless, challenges remain to promote currently available technologies and develop more economic and broadly available technologies for deployment of CCS. The Department's research programs and efforts have spearheaded R&D that would not have occurred otherwise and has successfully leveraged private investment in advancing the readiness of these emerging clean coal technologies.

Mr. Chairman, and members of the Subcommittee, this completes my prepared statement. I would be happy to answer any questions you may have at this time.