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Thank you, Mr. Chairman and Members of the Subcommittee. I appreciate this opportunity to provide testimony on the United States Department of Energy's (DOE's) research efforts in carbon capture and storage (CCS), with a particular focus on carbon dioxide (CO_2) re-use technologies.

INTRODUCTION

Fossil fuel resources represent a tremendous national asset. An abundance of fossil fuels in North America has contributed to our Nation's economic prosperity. Based upon current rates of consumption, the United States has approximately a 250-year supply of coal. Making use of this domestic asset in a responsible manner will help the United States to meet its energy requirements, minimize detrimental environmental impacts, positively contribute to national energy and economic security, and compete in the global marketplace.

Fossil fuels will play an important role in our Nation's future energy strategy throughout the remainder of this century. A key challenge to the continued use of fossil fuels, especially coal, will be our ability to reduce greenhouse gas emissions from fossil fuel processes. By developing technologies to mitigate the release of CO_2 into the atmosphere, we can continue to use our extensive domestic coal resource, while reducing the potential impacts on climate change. CCS can play a central role in fossil fuels remaining a viable energy source for our Nation. CCS is the primary pathway DOE is pursuing to allow continued use of fossil fuels in a carbon-constrained future.

COAL RESEARCH AND DEVELOPMENT PROGRAM

The coal research and development program – administered by DOE's Office of Fossil Energy and implemented by the National Energy Technology Laboratory – is designed to address environmental concerns over the future use of coal by developing a portfolio of revolutionary CCS technologies. In partnership with the private sector, efforts are 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 the urgent need on CCS technologies. The program is focused on two major strategies:

1) Capturing and long-term storing greenhouse gases; and
2) Substantially improving the efficiency of fossil energy systems.

The first strategy will reduce emissions of CO_2 from fossil energy systems. The second strategy will improve the fuel-to-energy efficiencies of fossil-fueled plants, thus reducing pollutant emissions, water usage, and carbon emissions on a per unit of energy basis. The improved efficiency strategy also provides a positive efficiency impact to partially offset the efficiency penalty incurred when CCS is added to a plant. Collectively, these two strategies comprise the coal research and development program's approach to develop technologies that will help current and future fossil energy plants meet requirements for a safe and secure energy future.

Coal research has resulted in important developments and insights regarding future technology innovations. New engineering concepts have been developed to convert coal into gases that can be cleaned and then used to generate power or produce fuels. New approaches to low-emission power generation are emerging that hold promise for integration with coal-based or combined coal-and-biomass energy plants. Technologies for achieving CCS are stretching beyond basic research, defining pathways in which greenhouse gas emissions can be permanently diverted from the atmosphere. With these building blocks, a new breed of coal plant can be created — one that generates power and produces high-value energy with dramatically reduced environmental impact. The Department's activities are focused on high-priority CCS enabling technologies, such as advanced integrated gasification combined cycle, advanced hydrogen turbines, carbon capture and storage, coal-to-hydrogen conversion, and fuel cells. These research areas provide the supporting technology base for all CCS development.

CARBON CAPTURE AND STORAGE

The coal research and development program is addressing the key technology challenges that confront the wide-scale deployment of CCS through research on cost-effective capture technologies; measuring, monitoring, verification, and accounting technologies to ensure permanent storage; permitting issues; liability issues; public outreach; and infrastructure needs. As an example, it is estimated that today's commercially available CCS technologies would add around 80 percent to the cost of electricity for a new pulverized coal plant, and around 35 percent to the cost of electricity for a new advanced gasification-based plant.[1] The program is aggressively pursuing developments to reduce these costs to less than a 10 percent increase in the cost of electricity for new gasification-based energy plants, and less than a 35 percent increase in the cost of electricity for pulverized coal energy plants.

The coal research and development program has been performing CCS field tests for many years. For example, the Regional Carbon Sequestration Partnerships are drilling wells in potential storage locations and injecting small quantities of CO_2 to validate the potential of key storage locations throughout the country, as well as conducting large-scale carbon sequestration field tests. Geologic sequestration projects at key locations across the country are being pursued. Substantial progress has occurred in the area of monitoring, verification, and accounting with the development and refinement of technologies to better understand storage stability, permanence, and the characteristics of CO_2 migration.

Research is also focused on developing technology options that lower the cost of capturing CO_2 from fossil fuel energy plants. This research can be categorized into three pathways: post-combustion, pre-combustion, and oxy-combustion. Post-combustion refers to capturing CO_2 from the flue gas after a fuel has been combusted in air. Pre-combustion is a process where a hydrocarbon fuel is gasified to form a synthetic mixture of hydrogen and CO_2, and the CO_2 is captured from the synthesis gas before it is combusted. Oxy-combustion is where hydrocarbon fuel is combusted in pure or nearly pure oxygen rather than air to produce a mixture of CO_2 and water that can easily be separated to produce relatively pure CO_2. This research includes a wide range of approaches: membranes, oxy-combustion concepts, solid sorbents, CO_2

[1] Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, U.S. Department of Energy/National Energy Technology Laboratory, DOE/NETL-2007/1281, Final Report, May 2007.

clathrates, and advanced gas/liquid scrubbing technologies. These efforts will produce meaningful improvements to state-of-the-art technologies and seek to develop revolutionary concepts, such as metal organic frameworks, ionic liquids, and enzyme-based systems.

A center piece of the program is DOE's field test program, carried out by the Regional Carbon Sequestration Partnerships. Each Partnership comprises state agencies, universities, and private companies, which are a "capacity building" enterprise with the goal of developing the knowledge base and infrastructure needed to support the wide-scale deployment of CCS technologies. Each Partnership is focused on a separate and specific region of the country with similar characteristics relating to CCS opportunities.

Collectively, the seven Regional Partnerships represent more than 350 unique organizations in 42 States, three Native American Organizations, and four Canadian Provinces. Collectively, these Partnerships constitute a significant national asset in that 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 in the country that can potentially be available for carbon sequestration. The non-federal cost share in the efforts being pursued by the Partnerships is greater than 35 percent, which is a key indicator of industry and technology vendor involvement that will help to ensure that developments are ultimately deployed. Together, the seven Partnerships form a network of capability, knowledge, and infrastructure to enable carbon sequestration technology to play a major role in a national strategy to mitigate CO_2emissions.

Over the course of these CCS activities, DOE will develop 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 CCS industry, and help transfer the lessons learned from the Department's program to current and future stakeholders.

CO_2 RE-USE TECHNOLOGIES

The coal research and development program has supported research on CO_2 re-use technologies for more than a decade. When 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 (EOR) and enhanced coalbed methane recovery (ECBMR) could play an important role in mitigating CO_2emissions. Although the CO_2 reduction potential of these approaches is limited, due to factors such as cost and market saturation of salable byproducts, 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 reductions that would be required to approach stabilizing greenhouse gas concentrations in the atmosphere.

EOR and ECBMR represent attractive beneficial re-use options for CO_2 that produce oil and natural gas while permanently storing the CO_2 in these geologic formations.

The Department has recognized the importance of CO_2 EOR for more than 40 years. As early as the 1970s, DOE-funded projects were developing concepts to improve the effectiveness and applicability of CO_2 EOR. DOE also has a long history in conducting research on the benefits of unconventional gas recovery with technologies such as coalbed methane recovery. Due in part to research conducted by DOE, coalbed methane production has increased for each of the last 15 years due to advances in production methods and now accounts for roughly 8 percent of the United States' natural gas production.

More recently, the Department has been studying the technologies needed to ensure permanence of CO_2 storage in "enhanced" coal bed methane recovery, where natural gas production is "enhanced" by injecting CO_2. The CO_2 displaces the methane on the coal surface and the CO_2 remains stored in the formation. Relative to CO_2 storage, current research activities in EOR and ECBMR now focus on developing reservoir management strategies to maximize and ensure permanence of CO_2 storage, while increasing oil/gas production; along with the development of technologies for measuring, monitoring, verification, and accounting that will validate permanent CO_2 storage in these applications while providing best practices and protocols for using these approaches as a carbon mitigation option.

Chemical conversion methods represent another technology approach that can be used for CO_2 re-use. CO_2 can provide the carbon source for many chemical reactions that range from producing mineral carbonates, to serving as chemical building blocks to make chemicals like methanol and urea, and ultimately making other organic chemicals, plastics, or composite materials that could have useful applications and represent long-term storage opportunities. Some industries that currently use relatively small quantities of CO_2 in their operations include metals; manufacturing and construction; chemicals, pharmaceuticals, and petroleum; rubber and plastics; and the food and beverage industries. Also, most of the baking soda (sodium bicarbonate) produced in the United States is manufactured by reacting soda ash with CO_2 and water.

The key hurdles to these new opportunities as potential CO_2 mitigation approaches relate primarily to cost and volume. CO_2 is a stable molecule; hence, chemical conversion to useful end products often requires expensive processes (high temperature and/or high pressure) that are not competitive with conventional manufacturing methods. These applications are also likely to utilize relatively small volumes of CO_2, as compared to the large volumes produced from power plants.

The Department had previously supported a working group for several years that consisted of several Universities and National Laboratories working on the science and economics of speeding the reaction of carbon mineralization as a potential option to permanently sequester CO_2. Carbonation reactions were investigated that combined CO_2 with alkaline earth elements (predominantly magnesium, but also calcium and other elements) derived from silicates to yield thermodynamically stable solid mineral carbonates – essentially, rocks. The team focused on conducting laboratory experiments and modeling the complex chemical reactions associated with this process. It was ultimately concluded that the process could not be cost effective as a CO_2 capture mechanism, and that numerous mining and storage issues also existed as key barriers. However, the knowledge-base gained from these efforts is proving valuable in pursuing applications where mineralization can be used to produce salable byproducts that might make this concept practical for a limited set of applications.

In the past few years, DOE has refocused research efforts on using mineralization chemistry as a possible means of "solidifying" CO_2 after it is stored in a geologic formation, thereby, ensuring permanent storage. A category of geologic formations called "Basalts" have emerged as leading candidates where this approach may someday have merit. Basalts are silica-rich volcanic rock that contains key minerals – such as calcium and magnesium – that can combine with CO_2 to form carbonates.

The Department is supporting the Big Sky Regional Carbon Sequestration Partnerships and Pacific Northwest National Laboratory in conducting research focused on enhancing the mineralization process in these formations. The Big Sky Partnership is conducting small-scale CO_2 injection in the Columbia River flood Basalts, with the goal of confirming feasibility of safe permanent storage in these formations. Successful research in Basalts could expand the viable geologic options for CO_2 sequestration in the continental United States, and provide unexplored options for CO_2 sequestration in developing countries that have extensive Basalt formations, such as India.

Biological capture of CO_2 through algae cultivation is another CO_2 re-use option that is gaining attention as a possible means to achieve reductions in CO_2emissions from fossil-fuel processes. Algae, the fastest growing plants on earth, can double their size as frequently as every two hours while consuming CO_2. Algae can be grown in non-arable regions, such as deserts, so as not to compete with farmland and forests, and they do not require fresh water to grow. Algae will grow in brackish water, plant-recycle water, or even in sewage streams, and, when cultivated within closed systems, these waters can be recycled, thereby minimizing further water use. Algae has the desirable feature of having a considerably high oil content, with yields of oil per acre that are orders of magnitude higher than those of traditional plant materials used to produce biofuels, such as ethanol or biodiesel. The oils in algae can be extracted and converted to liquid transportation fuel. While it is recognized that the CO_2stored by the algae will ultimately be released to the atmosphere, there is a net-CO_2emission decrease because the CO_2 released from coal combustion for algal growth reduces demand for petroleum without increasing coal consumption The coal is used to produce power and then again for algae production, hence, a net-carbon offset is realized by an increase in the energy extracted from the coal, compared to that same coal being used for power generation only.

A cost-effective, large-scale production system for growing algae using CO_2 from a power plant has not yet been demonstrated. DOE is sponsoring a project with Arizona Public Service (APS) to develop and ultimately demonstrate a large-scale algae system coupled with a power plant. APS is examining the use of coal gasification for the production of substitute natural gas. The utilization of algae for carbon management and recycle is an integral part of the project. The project has already proven the process at a small scale using a one-third acre algae bioreactor that has been operating for weeks using power plant stack emissions to produce sustained algae growth. Additionally, a prototype algae cultivation system is being evaluated for continuous operation. The project will ultimately assemble a fully integrated energy system for beneficial CO_2 use, including an algae farm of sufficient size to adequately evaluate effectiveness and costs for commercial applications. To complement the engineered system in Arizona, DOE has solicited Small Business Innovation Research proposals to explore novel and efficient concepts for several processing aspects of CO_2 capture for algae growth. Projects are addressing novel approaches for extracting oil from algae, and for converting algae oil to transportation fuel, focusing on technology consideration for integration with power or syngas production so as not to duplicate biofuels work being conducted by DOE's Office of Energy Efficiency and Renewable Energy. The results from these efforts should prove useful to future algae farming applications at power and synfuel plants.

THE AMERICAN RECOVERY AND REINVESTMENT ACT

The American Recovery and Reinvestment Act (Recovery Act) appropriated $3.4 ~~billion for~~billion for the Fossil Energy Research and Development (FER&D) Program. As reflected in the Joint Explanatory Statement of the Committee of Conference leading to the Act, these Recovery Act funds will support activities targeted at expanding and accelerating the commercial deployment of CCS technology, thus providing a key thrust to the FER&D Program to accelerate, by many years, the advances needed for future plants with CCS. Although specific details are still being worked on by DOE, CO_2 re-use technologies will be addressed in the following activities of the Recovery Act.

New CCS Initiative for Industrial Applications: $1.52 billion is to be used for a competitive solicitation for a range of industrial carbon capture and energy efficiency improvement projects, including innovative concepts for beneficial CO_2 re-use.

CONCLUSIONS

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. Advanced CCS technologies will undoubtedly play a key role in mitigating CO_2 emissions under potential, future carbon stabilization scenarios. CO_2 re-use 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. These re-use technologies, along with large-scale geologic sequestration, will contribute to the suite of options for reduction of anthropogenic CO_2 emissions.

DOE's research programs are helping develop these enabling technologies. The United States must continue to show leadership in technology development and future deployment to bring economic rewards and new business opportunities both here and abroad.

I applaud the efforts of this Committee and its Members for taking a leadership role in addressing these timely and significant issues.