



TECHNOLOGIES to Reduce or Capture and Store Carbon Dioxide Emissions

A report for the Secretary of Energy describing technologies to continue the evolution toward near-zero emissions from coal-based generation.

THE NATIONAL COAL COUNCIL
June 2007



COAL must continue its vital and growing role in energy production in the United States, supplying the energy for more than 50% of the nation's electricity production.

Reducing carbon dioxide emissions presents a significant technological challenge, but the coal industry has a proven record of successfully meeting such challenges.

It is imperative that research, development and demonstration efforts move forward quickly on a portfolio of technologies to reduce or capture and store carbon dioxide emissions.

Public-private support for technologies to reduce or capture and store carbon dioxide is critical to the United States energy independence and national security.

TECHNOLOGIES to Reduce or Capture and Store Carbon Dioxide Emissions

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The National Coal Council is a Federal Advisory Committee to the Secretary of Energy. The sole purpose of The National Coal Council is to advise, inform, and make recommendations to the Secretary of Energy on any matter requested by the Secretary relating to coal or the coal industry.



The Secretary of Energy
Washington, D.C. 20585

June 26, 2006

Ms. Georgia Nelson
Chair, National Coal Council
1730 M Street, NW
Washington, D.C. 20036

Dear Ms. Nelson:

Thank you for your May 4, 2006, letter stating that the National Coal Council (NCC) proposes to conduct a study of technologies available to avoid, or capture and store, carbon dioxide emissions – especially those from coal based electric utilities.

We understand that this report will expand upon the findings and recommendations of two previous reports submitted by the NCC entitled, "*Coal-Related Greenhouse Gas Management Issues*" (May 2003) and "*Opportunities to Expedite the Construction of New Coal-Based Power Plants*" (November 2004). We also understand that this report will focus on technologies available to the existing fleet of coal-based electricity generation plants as well as new and innovative technologies needed for future plants. It is also important for the discussion in the report to culminate in a recommended technology-based framework for mitigating greenhouse gas emissions from those plants.

In conjunction with industry and academic partners, the Department of Energy has already undertaken a great deal of research in the area of carbon capture and storage. Much of this work has been or will be conducted with the FutureGen Alliance, the Carbon Sequestration Regional Partnerships, the Carbon Sequestration Leadership Forum, and others. We encourage you to work with the members of these groups as closely as possible.

We also agree with your suggestion to assess the potential impact of the provisions of the Energy Policy Act of 2005 on the carbon management issue. It is our intention to use this study to provide a strong foundation for the continuing development of a technology based strategy for managing carbon and trust that it will act as a catalyst to promote additional public-private partnerships in the area of carbon capture and storage.

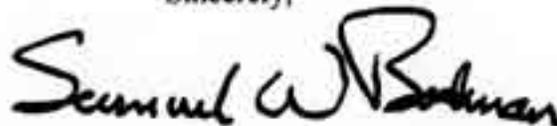
We believe that the NCC membership represents a broad spectrum of senior level industry, State, academic, and public interest organizations and is well positioned to complete this study.



I am designating Mr. Jeffrey D. Jarrett, Assistant Secretary for Fossil Energy, and Mr. George Rudins, Deputy Assistant Secretary for Clean Coal, to represent me in the conduct of this important study. Mr. Jarrett is available at (202) 586-6660; Mr. Rudins can be reached at (202) 586-1650.

I offer my thanks to the NCC for its efforts in assisting the Department of Energy in defining the scope of this study request. We look forward to receiving this study when completed.

Sincerely,

A handwritten signature in black ink that reads "Samuel W. Bodman". The signature is written in a cursive, flowing style with a large, prominent initial "S".

Samuel W. Bodman



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June 7, 2007

The Honorable Samuel W. Bodman
Secretary of Energy
U. S. Department of Energy
1000 Independence Avenue, S. W.
Washington, D.C. 20585

Dear Mr. Secretary:

On behalf of the members of The National Coal Council, we are pleased to submit to you, pursuant to your letter dated June 26, 2006, the report, "Technologies to Reduce or Capture and Store Carbon Dioxide Emissions." Technologies to reduce, capture and store carbon dioxide (CO₂) emissions are being developed in response to national and international concern about climate change. Even though many components of these technologies exist, significant additional research, testing, and eventually, operational experience at commercial scale electricity generating plants is needed. Technologies to address CO₂ emissions are at early stage of the technology development curve.

This report focuses on a broad suite of technologies to reduce, capture and store CO₂ emissions, primarily as they relate to direct coal combustion and also coal gasification and liquefaction. The report surveys and summarizes existing research, discusses relevant federal programs, makes recommendations regarding additional research opportunities and public policy objectives, and recommends a technology-based framework for mitigating CO₂ emissions from coal-based electricity generation plants.

It is evident that the Department of Energy is already at work to foster the development of these technologies. We would be remiss if we did not thank you for the Department's already significant efforts and valuable programs in this area. The report recognizes the scope of that work and in essence, concludes that much work still remains.

Coal will continue to play a vital role in energy production, not just in our country, but around the world. Reducing CO₂ emissions presents many significant technological challenges, but the coal industry has a proven record over the past 40 years of successfully meeting such challenges. Technologies to dramatically reduce particulates, sulfur dioxide (SO₂), oxides of nitrogen (NO_x), and metals continue to improve and provide benefits. With proper planning and research, technologies to manage CO₂ emissions likewise will be developed and deployed.

The Honorable Samuel W. Bodman

June 7, 2007

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These technologies cannot be simply willed into existence, but their development can and must be expedited. It is imperative that research, development and demonstration efforts move forward on a portfolio of technologies for CO₂ emissions control. And public-private partnerships should play a key role in speeding up the commercialization of these technologies.

Any framework for managing CO₂ emissions must take into account the realities of the existing infrastructure of energy production and use in our nation. Immediate opportunities focus on efficiency improvements within the current fleet of plants. These gains can be made at several points within the system and include turbine blade upgrades, condenser system and boiler feed water system improvements, washing and cleaning the coal that is used and improving the milling systems used to grind the coal. The development of regulatory incentives would dramatically speed up achievement of these efficiencies.

Along with a focus on existing plants, we must take advantage of efficiency gains that can be achieved in new plants. The use of supercritical, ultra-supercritical, integrated gasification combined cycle and other advanced clean coal technologies can raise the efficiency of new plants substantially. Also, streamlining the permitting process for new plants can reduce construction costs and provide incentives for operators to employ these cleaner technologies.

But, ultimately, a robust commitment to developing carbon capture and storage (CCS) technologies is required. Technology for CCS, including storage sites and related infrastructure, must be developed within the next 10 years. Legal liability questions must be answered during this time period as well. Several major CCS projects must be started as soon as possible so as to achieve commercialization within the next 15 years. Ideally, all of this will be done within the context of public-private partnerships in order to more quickly bring these technologies to the marketplace. These technologies will be implemented as they become available, affordable, and deployable.

Thank you for the opportunity to conduct this study. We believe it responds thoroughly to your letter of request, and the Council stands ready to answer any questions on its content.

Sincerely,



Georgia Nelson
Chair
The National Coal Council
President and CEO
PTI Resources, Inc



Mike McCall
Chair
The National Coal Council Study Group
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TXU Wholesale



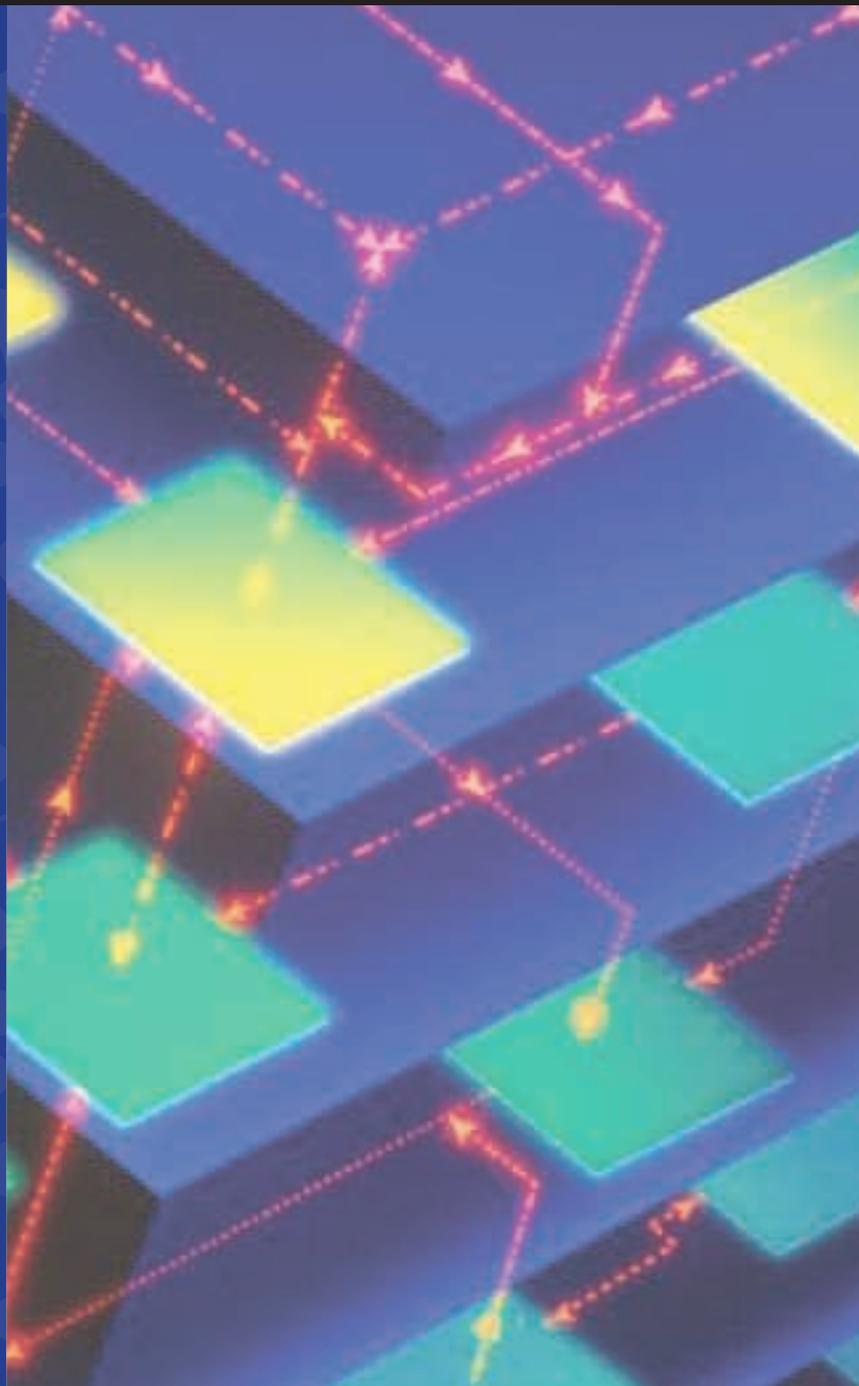
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THE NATIONAL COAL COUNCIL

TECHNOLOGIES to Reduce or Capture and Store Carbon Dioxide Emissions





EXECUTIVE SUMMARY

By letter dated June 26, 2006, Secretary of Energy Samuel W. Bodman asked the National Coal Council (NCC) to “conduct a study of technologies available to avoid, or capture and store, carbon dioxide emissions – especially those from coal-based electric utilities.” He also requested that the report “culminate in a recommended technology-based framework for mitigating greenhouse gas emissions from those plants.” The full text of Secretary Bodman’s letter can be found on page III.

In response to the first task, this report examines a suite of technologies focused on carbon dioxide (CO₂) emissions management. The study provides a current status overview of key technologies, describes the challenges they face in development and commercialization, and makes findings and recommendations concerning what needs to be done to make these technologies available in the marketplace.¹

The second task, recommending a framework for mitigation of greenhouse gas emissions, has its foundation in the response to task one. The framework discussion begins on the following page, but it also is embodied in the report Conclusions and the specific NCC Recommendations found at the end of the Executive Summary.

The Council accepted these tasks. The coal industry stands ready to rise to the challenges and concerns about carbon dioxide emissions. The industry has successfully managed to address emissions of sulfur dioxide (SO₂), oxides of nitrogen

(NO_x) and is now tackling mercury. Although they should not be expected to develop overnight, vigorous research, development and demonstration efforts can bring about a suite of technologies that are available, affordable and deployable. It is imperative that significant progress be made on these technologies so that any carbon management programs enacted by the government can be achieved.

STUDY MISSION STATEMENT

This report focuses on technologies to avoid, reduce, capture and store CO₂ emissions, primarily as they relate to coal combustion and gasification in the United States. The intent of this report is to:

- » examine a suite of technologies, providing current status and challenges, from which companies can investigate the most appropriate applications for specific needs and conditions
- » survey and summarize existing research
- » discuss relevant federal programs
- » make recommendations regarding additional research opportunities and public policy objectives
- » recommend a technology-based framework for mitigating greenhouse gas emissions from coal-based power plants

¹ The findings and conclusions in this report also build upon the knowledge gained from the previous NCC report, “Coal: America’s Energy Future,” issued in March 2006.

TECHNOLOGY-BASED FRAMEWORK FOR MITIGATING GREENHOUSE GASES FROM COAL-BASED ELECTRICITY PLANTS

Any framework must be based on the realities of the existing infrastructure of energy production and consumption. It is a near certainty that the use of coal will continue to grow worldwide over the next 25 years. In 2003, the world used 5.4 billion tons of coal, equal to about 96.2 million tons a week. By 2030, coal use is estimated to reach 10.5 billion tons a year, almost double the current use. Investments in technology offer the opportunity to accommodate the world's growing need for affordable energy while reducing CO₂ emissions and other environmental impacts.

The 2030 projection is on its way to reality. From 2003-2010 alone, the Energy Information Administration (EIA) has reported over 100,000 megawatts (MW) of coal-based power generation has been or is being built in China. These are not “planned” or “projected” megawatts; they are plants that have already been built or are under construction. Further, from 2010-2015, EIA forecasts another 90,000 MW of coal-based generation will be built. Many of these plants are also under construction. Add to this the new coal plants being built in other countries with a large indigenous supply of coal, such as India, Indonesia, Russia and the United States, and it is easy to see that the 2030 projection is well on its way to reality. Even Japan, which relies mostly on imports, is projecting a dramatic increase in the use of coal during this period. Given this huge world-wide demand for coal and other fossil fuels, control of greenhouse gas emissions must be based on technologies that can cost-effectively reduce or capture and store CO₂ emissions.

The nation must pursue CO₂ management technologies and policies that allow economic growth, support development and demonstration of

technologies to improve efficiency, capture CO₂, and transport and store CO₂. The nation will benefit from technologies that can simultaneously address climate change, reduce emissions and improve energy security.

TECHNOLOGY MATURATION

All technologies have a maturation curve. Experience teaches that early in development of new technologies, predicted costs and construction lead times for initial full-scale projects are often underestimated because forecasts tend to be based on optimistic lab-scale projections. Although engineering-economic studies of advanced coal and carbon capture and storage (CCS) technologies attempt to take this into consideration, initial full-scale applications may still be costly until experience provides a basis for accurate performance, reliability and cost projections.

Large capital-intensive technologies tend to have longer development cycles. This is due to the sheer time and expense for each “design and build” iteration (compare, for example, the time-to-market difference between a power plant technology and a computer chip). For high-efficiency coal and CCS technologies, the design and construction cycle is three to five years – not counting the potential for delays in permitting. Even if all goes well, the technology will take several cycles to mature to the “nth” plant cost level. Cost estimates for commercial-scale demonstration units can often double in constant dollars from early research projections. Costs are often highest at the point of the first full-scale demonstration, when components, systems, controls and test programs are truly integrated for the first time. Costs eventually decline as benefits accrue from economies of scale, design improvements, efficiency upgrades, experience-based learning, and competition. This process has been studied for many technologies in the electric utility and other industries.

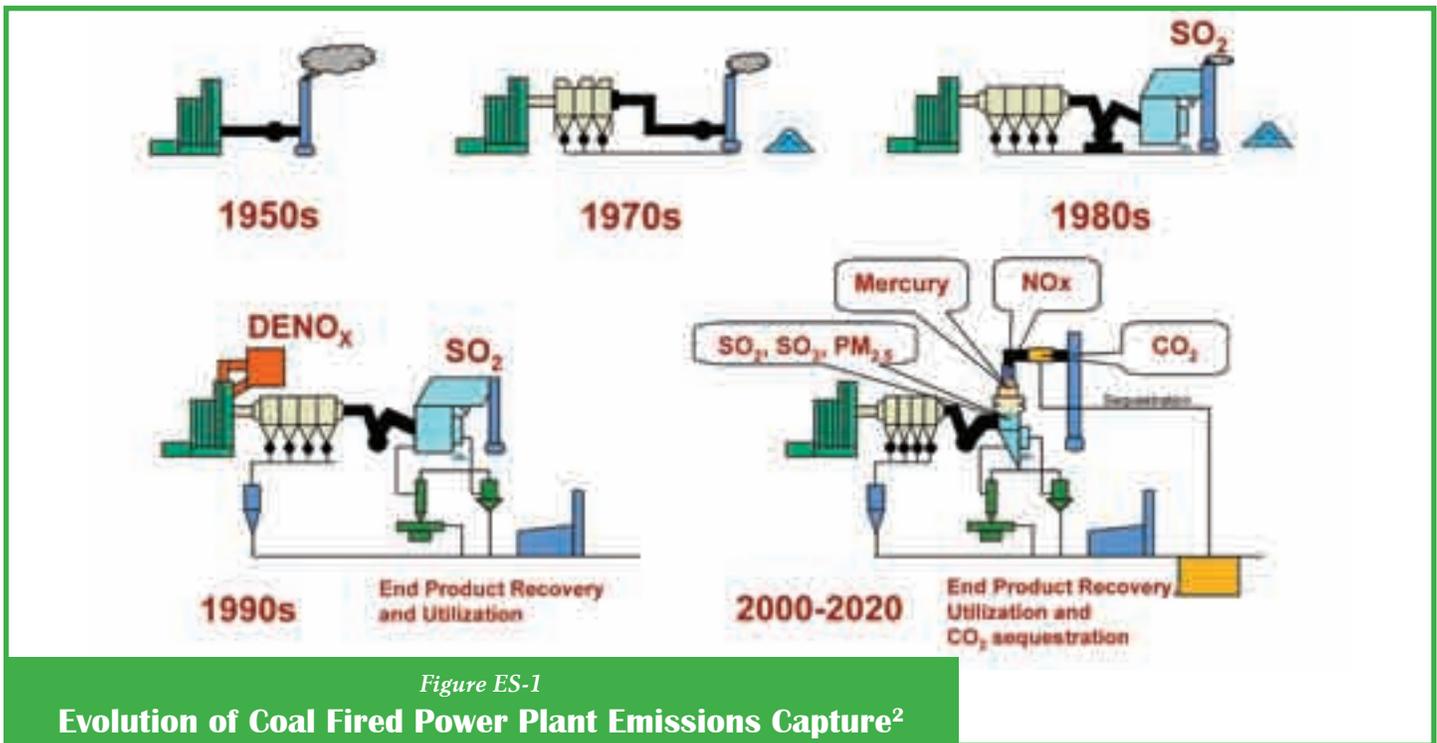


Figure ES-1

Evolution of Coal Fired Power Plant Emissions Capture²

The history of flue gas desulfurization (FGD) technologies, in the U.S. is a prime example. *See Figure ES-1.* In the early 1970s, FGD systems (commonly referred to as “scrubbers”) were not very reliable or efficient. As experience was gained over time, efficiencies increased from about 70 percent removal of SO_2 to today’s 95-98 percent. Reliability has also improved such that if the plant is running, the scrubber is running. But achieving this success took 20 years. Similar time periods to achieve success can be found with technologies to remove NO_x , and now technologies to remove and monitor mercury are in the early stages of a similar maturation curve. The drivers in both the SO_2 and NO_x cases were the same: sound, science-based technology R&D and regulations which recognize technology development and maturation. Both drivers also will be needed for the deployment of CCS.

A maturation curve for CCS technologies will similarly take time. Although some CCS technologies

are commercial at smaller scale in other industries, these require substantial re-engineering and scale-up for power applications. Other promising novel CCS technologies are in their infancy. Based on advances to date, however, accelerated technical and financial support could make a suite of these technologies commercially available within the next 15 years. Commercial maturity may take an additional decade. CCS technology development can be expedited, but not willed into existence overnight by changes in policy.

• MATURITY TAKES TIME

Commercial maturity could take an additional decade. CCS technology development can be expedited, but not willed into existence overnight by changes in policy.

² Ohio Coal Development Office

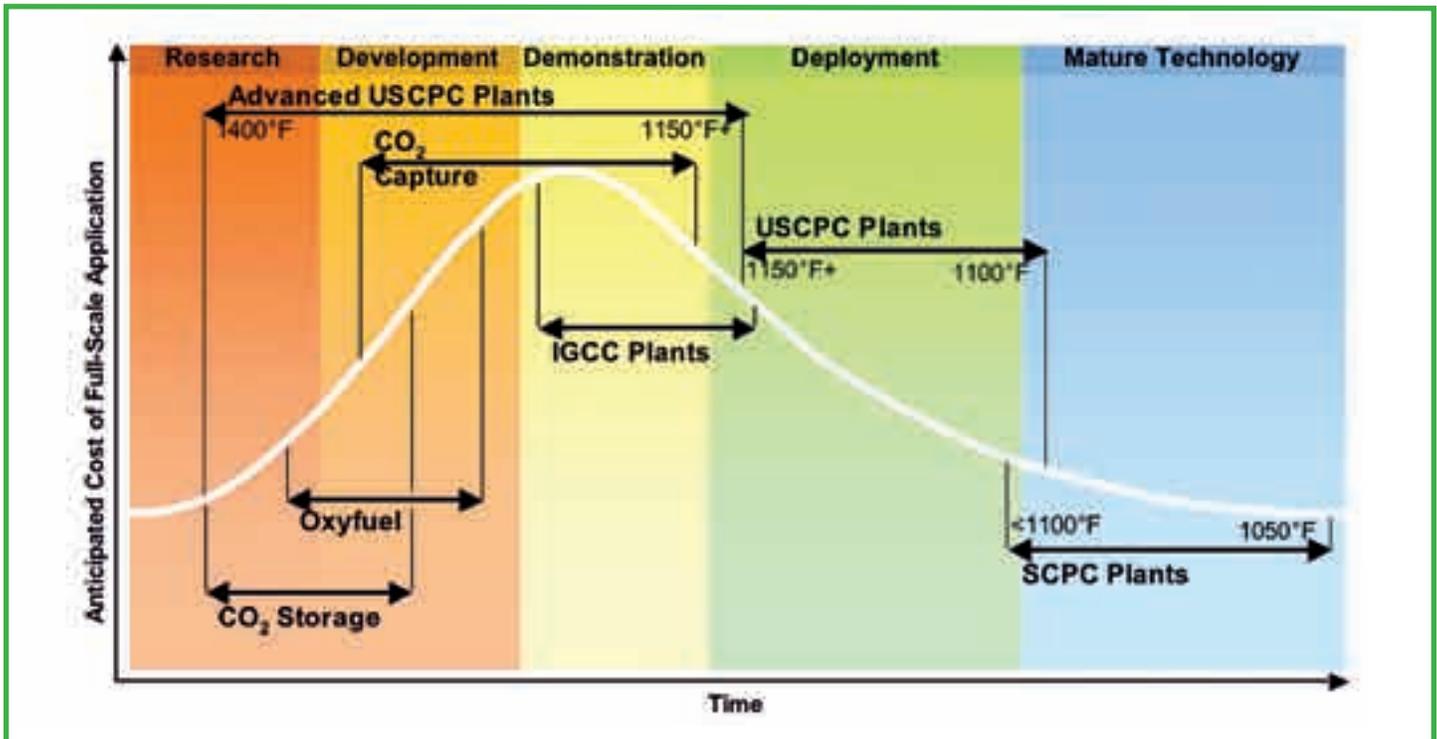


Figure ES-2

New Technology Development Curve for Coal³

Figure ES-2 depicts the relative developmental state of the major advanced coal and CCS technologies. This topic is explored further in Section 6.

HERE AND NOW

CO₂ mitigation technologies that are commercially feasible today are based on efficiency gains that can be achieved at existing plants and built into new plants. For existing plants, several technologies are available that can be retrofitted. In May 2001, the National Coal Council produced a report at the request of then-Secretary of Energy Bill Richardson (submitted to his successor, Secretary Spencer Abraham), which identified technologies that at that time could increase the amount of electricity from the existing fleet of coal plants by 40,000 MW. The approach set forth in those recommendations remains

viable today although many of those opportunities may have already been implemented. To some extent, those strategies will also result in corresponding reductions in CO₂ production. While the 2001 study did not specifically address carbon emissions, and not every unit is a good candidate for every technology, the potential energy savings at a given plant can range as high as 10 to 12 percent, with typical efficiency opportunities that are perhaps half that level. A 5 percent improvement in the efficiency of the overall coal fleet would equate to about 100 million metric tons per year of reduced CO₂ emissions.

These efficiency gains can be made at various points within these plants. They include steam turbine blade upgrades, improvements in condenser systems and boiler feed water systems, and in the milling systems used to grind the coal. In addition, the use of coal cleaned to higher quality levels can

³ Various PowerPoint presentations, EPRI, April 2007.

increase efficiency. The recommendations can be found in the Council report, “Increasing Electricity from Coal-Fired Generation in the Near-Term.”

Plant efficiency upgrades are a practical, quick and less expensive way to reduce CO₂ emissions in the near term. Given current clean air regulations, however, many power plant owners would not initiate helpful upgrades because of concerns that such improvements would trigger more expensive plant upgrades because of New Source Review (NSR). Dialog between the U.S. Department of Energy (DOE) and the Environmental Protection Agency (EPA) on how best to achieve progress on this issue would be beneficial.

UPGRADE CONCERNS

Power plant owners may be reluctant to take steps to improve efficiency and reduce CO₂ emissions for fear that these improvements could trigger NSR requirements leading to large and expensive plant modifications.

THE IMMEDIATE FUTURE

Another key to a real, technology-based framework is to address new plant construction. This report discusses several advanced clean coal technologies that are in the marketplace today and available to mitigate greenhouse gas emissions. During this initial period, before CCS technologies become readily available, energy efficiency is the best method to reduce carbon emissions. These include, but are not limited to, integrated

gasification combined cycle (IGCC) technology and ultra-supercritical combustion technologies. These technologies can increase plant efficiencies from the 33-35 percent range up to as high as 45 percent for centralized power plants.⁴

The main issue surrounding these technologies centers on the fact that they are more expensive to build and, in some cases, operate than the traditional subcritical pulverized coal plants. Past incentives to expedite the use of these technologies have focused on this cost issue, either through government grants or loans or cost-sharing partnerships. And as these technologies mature, investment tax credits are needed to speed deployment while initial costs are high. While these incentives have their use, and should continue, other incentives for building plants using these advanced technologies should be provided.

For example, the actual construction of a plant takes 36-42 months. The permitting process adds as much as five years. An unintended consequence of today’s process is that long permitting times delay replacing older technology with newer, more efficient and cleaner technology. One way to address this issue would be to significantly streamline the permitting process. This would still allow stakeholder input, but upon a final decision, the permits would be issued and the plant built, making the total project cost much less and the time for cost recovery to the company much shorter. The end result would be more power plants using advanced clean coal technology and mitigating greenhouse gas emissions through efficiency gains.

⁴ Centralized coal-fired power plants have traditionally operated at about 30 percent efficiency on a higher-heating value (HHV) basis. Thus, HHV efficiencies in the 40 percent range or higher represent a significant improvement.



REAL DEMONSTRATION PROJECTS

One of the most successful technology-based programs in the nation's history was the Clean Coal Technology program initiated in 1985. Successors to this program continue today, but for the most part the program was completed by 2000. Over that 15-year period, major technologies were researched, developed, demonstrated and deployed at numerous coal-based electricity plants around the country. Any successful framework must include a similar commitment to CCS technologies. Demonstration projects for a new level of ultra-supercritical power plants would also be appropriate because the plant requires the development of new high alloy materials that would carry a capital expense premium with, at least in the first instance, no real guarantee of the long-term efficiency and reliability necessary to justify the increased costs. The potential overall efficiency gains and accompanying environmental benefits should more than justify policies to support initial demonstrations of these technologies.

Several CCS projects need to be initiated under real world conditions and at real world scale. An example is the recently announced American Electric Power (AEP) decision to install Alstom's new post-combustion technology, known as chilled ammonia, for capturing CO₂ emissions from two existing plants. Starting with a "commercial performance verification" project in mid to late 2008 in West Virginia, AEP will move to the first commercial-sized project at one 450-MW coal-fired unit at Northeastern Plant in Oklahoma by late 2011. This would capture about 1.5 million metric tons of CO₂ a year, which will be used for enhanced oil recovery. The West Virginia project will include storage of CO₂ in deep saline reservoir formations beneath the plant site, based on work by Battelle funded primarily by \$7 million in contributions by the DOE at the same time. Another project announced by AEP at the same time is the installation of Babcock & Wilcox's oxy-coal technology at full scale on another power plant. The commercial scale plant is expected to be in service in the 2012-2015 timeframe, with the captured CO₂ likely to be stored in deep geologic formations. The storage portion of each of these

projects involves a partnership with Battelle. These are just two technologies, at three plants, involving a small number of companies. Additional projects are essential to moving a competitive suite of clean coal technologies forward. Next-step projects need to be diverse in terms of geographic location, type of clean coal technology, and method of CO₂ storage.

The DOE can facilitate many similar projects, and must lead and expedite any framework for mitigating greenhouse gas emissions. These projects should be initiated as soon as possible to produce in the next five years operational data that will allow companies to choose the best applications for their needs from a full menu of options based on engineering, economics and geography/geology. A framework needs to include small-scale projects, such as CO₂ injection into geological formations coupled with long-term monitoring, to provide a strong foundation for future CCS deployment, as well as large-scale demonstrations that can fully test and evaluate the integration of generation, capture, transportation and storage technologies.

RETROFIT PROJECTS

AEP, in partnership with Alstom, Battelle, and B&W have announced three separate CCS projects. A chilled ammonia “commercial performance verification” project with deep saline reservoir storage planned to be operational in 2008 in West Virginia. The project is expected to be scaled up and installed with EOR on a 450 MW unit in Oklahoma by 2011. Oxy-coal with deep saline storage is also planned to be in service in 2012-13 timeframe.

A SERIOUS DISCUSSION

Coal is not the only source of greenhouse gas emissions, nor is it the only source for electricity in the nation. Any framework for mitigating greenhouse gas emissions must involve the full energy spectrum. With the projected growth in energy consumption, the country will need every ton of coal, cubic foot of natural gas, pellet of uranium, wind turbine, solar panel and Btu it can produce. Increased efficiency will also need to provide a significant and meaningful contribution.

A framework for mitigating greenhouse gas emissions has to seriously address the broad context of energy production and use. It is forecast that the nation will increase its energy consumption dramatically by 37 percent over the next 25 years. Renewable energy, along with end-use energy efficiency and demand side management, will continue to play an important and growing role in meeting this increased demand for power. Renewable energy sources such as wind, solar and biomass, however, simply cannot meet the projected electricity production or reliability the nation's economy requires. The bulk of the country's near-term electricity demand will continue to be met with coal-, nuclear- and natural gas-based generation. Coal will continue to supply about half the nation's electricity well into this century.

Solutions to meet the future energy needs of this nation must also recognize national security concerns. Coal is domestically available in large quantities, can be safely and securely transported around the country, is less subject to foreign market pressures in terms of cost or availability, and its use has become increasingly cleaner with innovation and technology development. Any serious discussion of coal's future role in a carbon-constrained world must include the fact that while its use has doubled over the past 35 years, emissions such as SO₂ and NO_x have markedly decreased. According to the U.S. EPA's Annual Trends

Report, this country's air is the cleanest it has been since the end of World War II.⁵

LOOKING TOWARD THE FUTURE

The framework for mitigating greenhouse gas emissions is simple conceptually – but difficult in terms of marshaling the requisite financial commitments, resolving legal and regulatory uncertainties, and instituting appropriate risk-sharing mechanisms. Necessary actions include:

- » **Near Term:** Efficiency improvements at existing plants should be expedited. This can be achieved both technically and economically, but regulatory barriers must be addressed including modifying the NSR process. In such cases, NSR should not be triggered for plant efficiency improvements that reduce CO₂ emissions with no subsequent increase in SO₂ or NO_x emissions.
- » **Mid Term:** Advanced clean coal technologies such as IGCC and ultra-supercritical combustion must be given public policy support in the form of cost and permitting incentives and financial support for initial demonstrations so they can succeed in the marketplace. Legal questions about liability for long term storage must be addressed. Sure-footed and steady progress on the FutureGen project is very important.
- » **Long Term:** Technology for CCS, including storage sites and related infrastructure, must be developed and demonstrated over the next 10 years. Several major CCS projects must be started as soon as possible in order to achieve commercialization within the next 15 years. Oxygen firing technologies are designed

specifically for carbon capture and will not develop independently of storage and infrastructure.

Ideally, all this is done in the context of public-private partnerships to more quickly bring these technologies to a state of commercial deployment.

Within the next 15 years, a suite of carbon capture technologies and storage facilities must become commercially available and affordable. When this happens, the coal-based electricity generation industry will be able to build these technologies into new plants and retrofit these technologies at existing plants where appropriate. In the long run, when these technologies become available in the marketplace, other nations using coal can also access them at more reasonable cost.

REPORT CONCLUSIONS

In support of the above framework for mitigating greenhouse gas emissions, the National Coal Council encapsulates the key conclusions from the report that follows:

Section 1 World Energy and Greenhouse Gas (GHG) Emissions Context

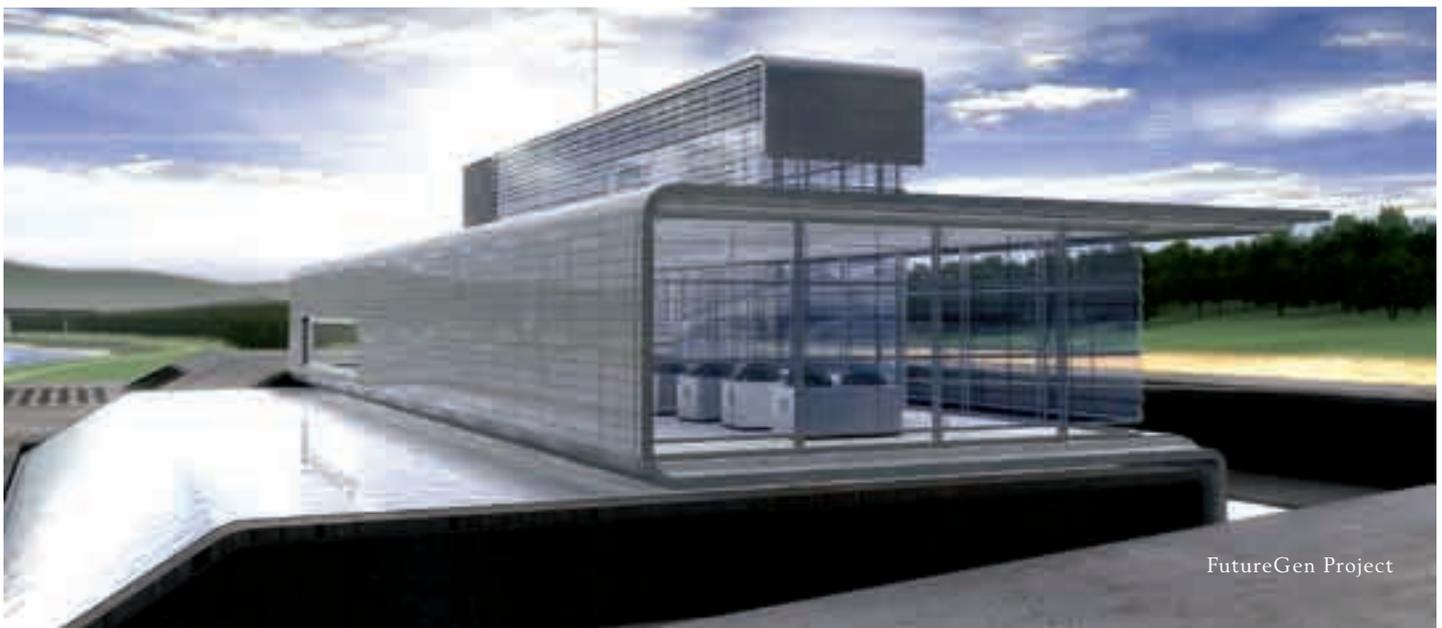
- » The nation must pursue climate change policies that allow economic growth, support development and demonstration of technologies to improve efficiency, capture greenhouse gases, and transport and store carbon dioxide. The nation will benefit from technologies that can simultaneously address climate change, reduce emissions and improve energy security without damaging the domestic economy or the ability of U.S. business to compete in the global market.

⁵ U.S. Environmental Protection Agency Air Quality Trends Report, 1940-2005

- » The coal and power industry will continue to develop CCS technologies for all generation types (advanced coal combustion and gasification technologies), but needs incentives to be able to do so within the timeframe the technologies are needed to address the climate change issue.
- » The U.S. must develop strategies to help developing nations adopt CCS technologies as well. By ardently pursuing the required RD&D, these technologies will advance more quickly, thus becoming more cost effective and attractive to developing nations.
- » When the costs of CCS technologies are driven down to economically feasible levels, they will be deployed.

Section 2 Technologies to Reduce Carbon Dioxide

- » New high-efficiency power plant designs using advanced pulverized coal combustion and gasification could reduce (compared to existing coal plants) more than 500 million metric tonnes (MMt) of CO₂ over the lifetime of those plants, even without installing a system to capture CO₂ from the exhaust gases.
- » Currently available, commercially-proven technologies can significantly increase the efficiency of domestic electric power generation and thereby reduce the emission of CO₂ and regulated air pollutants such as SO₂, NO_x, mercury and particulates. Pulverized coal and gasification plants announced or beginning construction today have improved efficiencies -- about 25 percent better relative to the average of existing power plants, with correspondingly better environmental performance.
- » For units already in operation, improvements in efficiency offer opportunities to reduce CO₂ emissions. Retrofits are normally undertaken to bring about efficiencies and reduce emissions, but in some cases, required upgrades to emissions equipment may use a significant amount of parasitic energy and thus offset any corresponding energy efficiency gains, possibly resulting in lower overall unit efficiencies.
- » The use of coal cleaned to higher quality levels offers the potential to both reduce pollutants such as particulates, mercury, and SO₂, as well as increase efficiency.



- » The U.S. generation industry will require a portfolio of highly efficient advanced clean coal technologies to provide competitive options for the range of domestic coals. Continued support of RD&D and deployment for the identified potential solutions for PC, circulating fluidized bed combustion (CFBC) and IGCC technologies to determine actual cost and reliable performance is critical to achieving low-cost, reliable and clean coal-based power.
- » Continuing RD&D for advanced materials capable of handling the higher temperatures and pressures of ultra-supercritical plants is needed.
- » Variances in plant designs and fuel characteristics prevent “one-size-fits all” solutions for all plants. A portfolio of clean coal technologies will be needed in the future. It is too early in the research stage to assume which technologies will be the most promising.

Section 3 Technologies for Capturing Carbon Dioxide

- » Expedited demonstration of first-generation technologies for CO₂ capture is needed. Streamlining this process so the research proceeds from laboratory pilot to demonstration phase is necessary so these technologies will be available to meet future climate change regulations.
- » Given the magnitude of the challenges associated with CO₂ reduction and capture, RD&D is needed on a wide range of new concepts and technologies that may provide economic solutions for carbon management.
- » For advanced combustion, most opportunities for significant improvement are found in the capture process itself. For IGCC, the capture process is expected to be more efficient (compared to PC), but there are opportunities for improving the overall generation efficiency through enhanced integration between the gasification and power generation areas of the plant, better heat recovery, and through improvements in the production of oxygen in the air separation unit.
- » More work should focus on demonstrating advanced technologies for CO₂ compression systems that lower the capital cost and energy requirements. Compression is expected to consume up to 8 percent of the electricity produced by a power plant and is common to nearly all CO₂ capture requirements. Improved compression systems would enhance the cost effectiveness of CO₂ capture for carbon capture systems currently being considered.
- » Designers of CO₂ recovery systems should evaluate the use of waste heat recovery from the CO₂ compression systems to improve process efficiency. The effective use of the waste heat required from interstage cooling of the CO₂ during compression will improve the overall efficiency of both flue gas treatment systems for combustion-based systems and treatment of syngas for IGCC systems.
- » FutureGen is a vital program and the industry looks forward to its continued development. It is such a strong model that a case can be made for a parallel program aimed at development of zero emission technologies for coal combustion plants that will also produce strong benefits domestically and internationally.

- » Government has an important role in development and commercialization of energy technologies. Given the global interest in carbon capture technologies, it will be important for U.S. industries to be at the center of these important technological developments. Developing the technologies to improve efficiency and become the building blocks of tomorrow's energy systems will also enhance U.S. energy security.

Section 4 *Carbon Management for Coal to Products*

- » Coal to products (CTP) technologies can produce a range of fuels and chemicals while generating significant amount of by-product electricity. CTP technologies can produce high quality liquid fuels, such as diesel, jet fuel, and gasoline with virtually no sulfur or particulates. Price volatility of oil and natural gas, however, is a key barrier to adoption of CTP technologies.
- » Government support through Department of Defense for CTP deployment should be encouraged for the following reasons:
 - o To create a secure source of domestic fuel production in the event that foreign oil supply lines are disrupted, and,
 - o To advance the development of CTP gasification technologies which will have co-benefits in advancing essentially similar technologies for carbon capture applications at power plants.
- » CTP can also produce pipeline quality natural gas that can be shipped through existing natural gas pipeline infrastructure. Producing gas from coal may avoid creating another dependency on foreign energy.

- » Long-term government contracts for CTP fuels and other government-private partnerships can mitigate risk and reduce economic barriers significantly. This will help attract the capital resources needed to build and grow CTP industries.
- » Co-processing biomass with coal, in combination with carbon capture and storage, may produce products that have significantly lower greenhouse gas profiles than conventional products, such as petroleum-based diesel or corn ethanol.
- » The use of CCS technologies can minimize CO₂ emissions from CTP production plants and result in life-cycle greenhouse gas emissions comparable to, or lower than, conventional petroleum-derived transportation fuels.

Section 5 *Carbon Dioxide Capture and Storage*

Progress in geological storage of CO₂ can be accelerated through a focused program of research and development in the following areas:

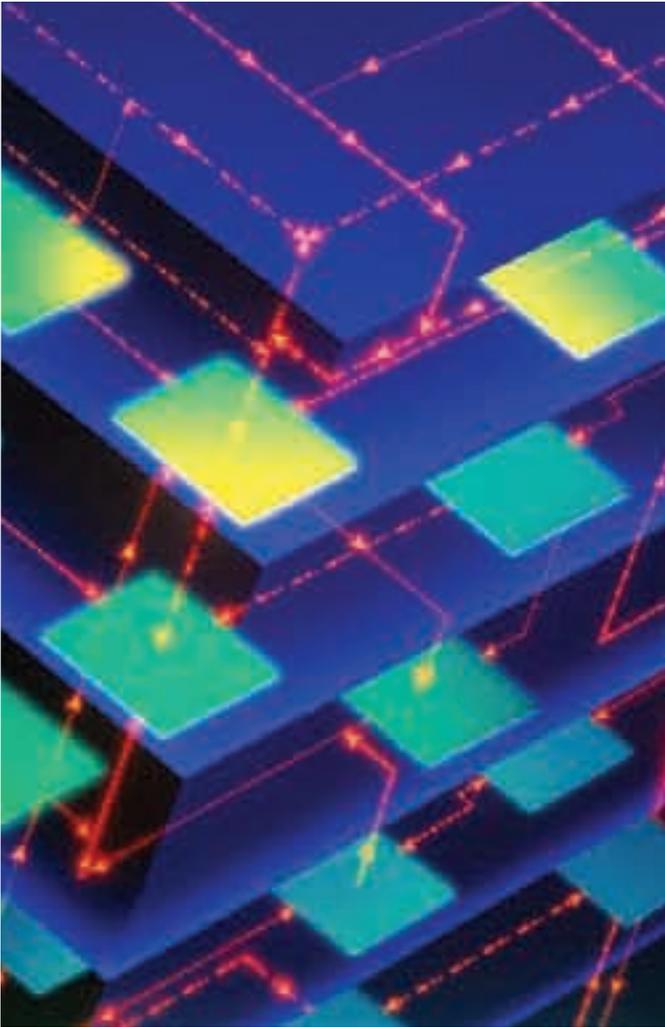
- » Multiple, large-scale demonstration sites for CO₂ storage in formations such as saline reservoir are needed in the U.S. to provide sinks for initial carbon capture projects, test monitoring methods and equipment, and identify legal, regulatory and practical concerns.
- » Further research is needed to gain greater insight and confidence in long-term storage mechanisms, such as solubility, capillary and mineral trapping, that increase storage security in the post-injection period; and methods must be identified for remediating storage projects that are not performing well in terms of injectivity, capacity and containment.

Key research areas include:

- Efficient methods for site characterization and selection – focusing on assessing injectivity, capacity and containment. This includes characterizing the seal, or caprock, of a storage formation over the large spatial scales needed for commercial-scale storage projects.
- Reliable methods for estimating the capacity and plume footprint (location of injected CO₂ projected on the land surface) for CO₂ stored in saline formations;
- Effective techniques for monitoring CO₂ plume migration and containment in the storage reservoir – and techniques to assess the rates and source of leakage should it occur.
- Reliable methods for assessing and mitigating the potential for abandoned wells to compromise storage integrity.
- » Development of a strong base of CO₂ pipeline design standards, with consistent national approval and permitting processes to provide public confidence.
- » Siting of power plants is a complex and lengthy process, integrating transmission access, ease of fuel transport, water and land use, by-product transport, etc. Successful implementation of carbon capture will add a significant additional level of complexity in siting due to the need to access acceptable storage or for pipeline to storage. It is critical that the addition of planning for CO₂ capture and sequestration does not add excessive time to the development of new generation capacity. Development of CO₂ pipelines and certification of storage sites needs to be a national priority, and should not be the sole responsibility of individual generation plant owners.
- » CO₂-enhanced oil recovery, with its industry experience, and existing regulatory protocols, provide an important commercial path for CO₂ storage, and a bridge to utilizing formations, such as saline reservoirs, that hold the largest potential for CO₂ storage.
- » Carbon capture and geologic sequestration will create potential long-term liabilities. Implementation of CCS would be in response to anticipated or existing government imposed limits on CO₂ emissions; therefore, these liabilities should not be imposed on the electric generators or coal producers. As such activities are done to serve the public good as determined by the government, the entities performing those activities should be provided a large measure of long-term risk reduction.
- » Deployment of agricultural management, forestry practices and wetland restoration for terrestrial carbon sequestration to reduce the rate of accumulation of CO₂ in the atmosphere while restoring degraded soils, enhancing biomass production and generating environmental co-benefits (e.g., improved water quality, biodiversity protection, land conservation, erosion reduction, etc.).
- » The nation should pursue all avenues of reducing CO₂, including further research into finding beneficial uses of carbon dioxide such as to spur algae growth and create biofuels.

Section 6 Technology Profiles and Trends

- » Analysis of the current state of CCS technology provides optimism that necessary advances can be made to meet goals for CO₂ capture and sequestration, but also emphasizes that success will require a stronger and more concerted and collaborative effort than is currently under way.



- » Achieving greenhouse gas emissions reduction goals will require a broad suite of advanced coal and CCS technologies that can be tailored to the conditions of each individual geographic location, electricity market structure, fuel source, etc.
- » **IGCC.** RD&D plans for IGCC with CO₂ capture provide a pathway toward realization of a roughly 30 percent reduction in the capital cost over the next 20 years on a constant dollar basis, while increasing net efficiency by 9 percentage points.

- The CO₂ capture process for gasification is considered commercially mature since it uses technologies that chemical industries have already developed for acid gas cleanup in coal- and petroleum-based gasification systems and in natural gas processing. However, using those technologies at large scale in IGCC power plants still constitutes a first-generation application. The technology has not been completely and efficiently integrated into a large-scale power plant and CCS system. Furthermore, hydrogen turbines have not yet been demonstrated in commercial-scale IGCC applications.

- The base IGCC technology is commercially available, but will benefit significantly from an accelerated RD&D effort to achieve efficiency, reliability and availability improvements, which also are required to meet the CURC-EPRI⁶ targets for pre-capture systems. Additional efforts will focus on adapting combustion turbines for use with hydrogen-rich fuels and on cost-effective integration.

- » **Pulverized Coal.** Current RD&D plans for advanced PC generation with CO₂ capture provide a pathway toward realizing a 30 percent reduction in the capital cost over the next 20 years on a constant dollar basis, while increasing net efficiency by 12 percentage points.

- For PC and CFBC technology with CO₂ capture, significant cost and performance improvements will need to come from work to improve energy-consuming solvent processes that separate carbon from exhaust streams. Current processes have high capital costs and high auxiliary power or steam demand.

⁵ Coal Utilization Research Council (CURC) and Electric Power Research Institute (EPRI)

- o Significant CO₂ management gains and cost reductions can also be achieved by improving the efficiency of the generation system with ultra-supercritical pulverized coal combustion and supercritical circulating fluidized bed combustion technology.
- » Regardless of the technology, experience teaches us that early in the development of new technologies, we often underestimate the costs and construction lead times for initial full-scale projects. Although engineering-economic studies of advanced coal and CCS technologies attempt to allow for this phenomenon, initial full-scale applications may prove to be more costly than expected. Eventually, accumulation of lessons-learned will bring substantial improvements in performance, reliability and cost.
- » For many of these technologies, timely attainment of the desired developments will require significant public policy and funding support to enable collaborative initiatives involving power producers, equipment manufacturers, government agencies, academic research organizations and others. Key elements include:
 - o predictable policies,
 - o sharing of cost and schedule risks,
 - o accelerated publication and incorporation of lessons learned.

Section 7 *Groups Engaged in Technology Development*

- » While funding for CO₂ capture and storage research has accelerated in recent years, it is insufficient to advance the commercialization of the technology at an acceptable pace, particularly

for large-scale stand-alone and integrated CCS demonstrations and for deployment of the technology.

- » Public/private partnerships work – the U.S. needs to accelerate these efforts.
- » The DOE National Energy Technology Laboratory (NETL) regional carbon sequestration partnerships are initiatives that are already in progress and advancing knowledge surrounding carbon sequestration technology.

Section 8 *Energy Policy Act of 2005 – Key Coal Provisions*

- » Given the early stage of development of technologies for carbon capture, compression, delivery, storage and monitoring, as well as the known track record needed to bring such technologies to maturity in the market, the National Coal Council recommends that DOE continue to support the many programs outlined throughout this report. As technologies mature, it will be even more important for DOE to support deployment of new technologies using all the tools at its disposal, such as financial incentives and favorable tax policies.
- » Also, because limited data exist for IGCC units operating on low rank coals, the Energy Policy Act of (EPACT) of 2005 encouraged increased investment in RD&D of IGCC plants using these coals to provide more accurate data on costs and performance. Given the growing importance of lower rank coals in U.S. electricity generation, this research should be continued for a range of gasification technologies, including slurry and dry feed gasifiers.



NCC RECOMMENDATIONS

The National Coal Council makes the following recommendations in the belief that the U.S. Congress will address carbon management in the near future. In that context, it is imperative that the nation immediately accelerate deployment of technologically and economically favorable high-efficiency advanced coal combustion, coal liquefaction and gasification technologies. In addition, it is critical to accelerate development, demonstration and deployment of CO₂ reduction and CCS technologies to control and sequester CO₂ emissions from these advanced coal-based technologies. These technologies will be implemented as they become available, affordable and deployable.

Therefore, the National Coal Council recommends that the Department of Energy, acting in coordination with other federal agencies and states, should:

- » Work closely with other appropriate agencies within the federal government to streamline the long, costly and complicated permitting process for siting, building and operating power plants and associated CO₂ capture, transportation and storage facilities.
 - o The EPA's New Source Review (NSR) regulations can impede retrofit applications at existing facilities and thus may block efficiency improvements and corresponding CO₂ benefits. A cooperative approach between DOE and EPA to facilitate the implementation of the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR). regulations, for example, would be extremely helpful.
- Ideally, reconciliation of all these programs into one clear and workable set of regulations would be very positive.
- EPA rules for implementing CAIR and CAMR should align with NSR regulations so that as existing power plants come into compliance with these rules, they are given incentives to simultaneously make efficiency improvements in plant operations.
- » Significantly ramp up RD&D funding across the full spectrum of CCS technologies (capture, compression, transportation, storage and monitoring) so as to ensure that the U.S. can meet industry, state and national expectations for capture and storage of CO₂.
- » Continue to fund and support these activities within the regional carbon sequestration partnerships:
 - o Create a team led by a senior member of DOE management to lead an engineering program for testing multiple CCS technologies at power plant scale within the next five years.
 - o Determine the legal liabilities associated with CCS. This includes resolving ownership issues and responsibility for stored CO₂ in the event of leakage, and implementing long-term monitoring of storage facilities.

- Increase funding of regional partnerships to adequately finance large-scale CO₂ storage projects in a number of different geologic formations, such as deep saline reservoirs and enhanced coal bed methane recovery. Current projects are focused strongly on enhanced oil recovery applications which enable a lower total cost, but further work needs to be done to prove the viability of other kinds of projects so as to represent a spectrum of geology in areas where CO₂ is generated.
- » Support RD&D projects that cover a wide variety of capture technologies, including those that capture less than 90 percent of the CO₂, because of the early stage in the technology maturation process. CO₂ capture rates will increase as the technology matures, and the nation should not abandon technologies today simply because they cannot immediately meet high CO₂ capture expectations early in the development cycle.
- » Pursue a large scale demonstration project to spur development of advanced ultra-supercritical pulverized coal power generation. Extremely high temperatures and pressures (1,400°F, 5,000 psi) are required to achieve high plant efficiency, which require the development of new alloys and components. Because of the cost premium necessary to develop new materials, financial support will be needed initially to demonstrate that this kind of advanced design is viable.
- » Promote significant additional research and demonstration projects related to the transportation and safe storage of CO₂ by coordinating with other federal agencies to:
 - Develop accepted performance standards or prescriptive design standards for the permanent geological storage of CO₂.
 - Foster the creation of uniform regulatory guidelines site selection, operations, monitoring and closure for storage facilities
 - Ensure creation of a federal entity to take title to and responsibility for long-term post-closure monitoring of underground storage, liability and remediation at all CO₂ storage sites.
 - Facilitate development of an economic, efficient and adequate infrastructure for transportation and storage of captured CO₂.
 - Create a legal framework to indemnify all entities that safely capture, transport and store CO₂, regardless of their size, and develop realistic initial expectations for CO₂ monitoring, measurement and verification.
 - Create clear transportation and storage rules that provide incentives to business models that will encourage the development of independent collection pipelines and storage facilities. Such rules must expedite the growth of independent businesses with a singular focus on CO₂ transportation and storage, rather than power plant operations.
- » Consider undertaking three to five projects (at both pulverized coal and IGCC plants) at a scale of about 1 million tonnes /year of CO₂ injection to understand the outstanding technical questions and to demonstrate to the public that long term storage of CO₂ can be achieved safely and effectively.



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