May 2000

RESEARCH AND DEVELOPMENT NEEDS FOR THE SEQUESTRATION OF CARBON DIOXIDE AS PART OF A CARBON MANAGEMENT STRATEGY

THE NATIONAL COAL COUNCIL

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The National Coal Council

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E. Linn Draper, Jr., Chairman

Robert A. Beck, Executive Director

U.S. DEPARTMENT OF ENERGY

Bill Richardson, Secretary of Energy

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 the Secretary of Energy on any matter requested by the Secretary relating to coal or to the coal industry.

June 11, 2000

The Honorable Bill Richardson
Secretary of Energy
United States Department of Energy
Room 7A-219
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Dear Mr. Secretary:

On behalf of The National Coal Council I am pleased to submit the enclosed report "Research and Development Needs for the Sequestration of Carbon Dioxide as Part of a Carbon Management Strategy". This report was authorized by you on May 5, 1999 and formally approved by The National Coal Council on May 3, 2000.

In order to respond to your request, the Council established a working group consisting of individuals with expertise in the relevant subject areas. The group was chaired by Council member James K. Martin, and included members of the Council as well as additional recommended experts. All participants held excellent credentials for completing this task.

This report focuses on the research and development opportunities and needs for sequestering carbon dioxide (CO_2). As such it examines ways to remove CO_2 which is currently present in the atmosphere, capture CO_2 emissions before they are released to the atmosphere, and increase the efficiency of electricity from coal-fired generation thereby limiting CO_2 emissions from that process.

Scientists, policymakers and the public in general must recognize and address the continuing importance of coal and other fossil fuels as a major source of energy well into the 21st century. This is true even in a world constrained by concerns about climate change.

For this reason it is imperative that CO_2 sequestration and generation efficiency become high priorities for Department of Energy research and development if the goal is to manage atmospheric concentrations of carbon while providing low-cost, reliable energy to drive the national as well as global economy. This report outlines these research and development needs.

Numerous technologies are discussed. Leadership, in the form of a partnership between government and industry, is needed in order to demonstrate these technologies on the scale which they are required. Costs must be reduced so that they are implemented.

Coal is the most abundant, economical domestic energy source our country has currently and will have for decades to come. In the past, regardless if the challenge was economic, technical or environmental, the nation has always responded to keep the energy we derive from coal as the backbone of our economy.

In continuing the response to yet another challenge, the funding for the research and technology into these sequestration and generation efficiency technologies must be increased, not decreased. The National Coal Council strongly recommends that the United States government led by the Department of Energy, in full cooperation with other departments and agencies and in partnership with the entire coal industry, implement a fuller and more aggressive carbon management program with a major component being research and development of cost-effective CO_2 sequestration and generation efficiency technologies.

The Council appreciates being asked to provide this report and stands ready to answer any questions you may have about it.

Sincerely,

Dr. E. Linn Draper, Jr.
Chairman

Enclosure

TABLE OF CONTENTS

PREFACE

The National Coal Council is a private, nonprofit advisory body, chartered under the Federal advisory Committee Act.

The mission of the Council is purely advisory: to provide guidance and recommendations as requested by the United States Secretary of Energy on general policy matters relating to coal. The Council is forbidden by law from engaging in lobbying or other such activities. The National Coal Council receives no funds or financial assistance from the Federal Government. It relies solely on the voluntary contributions of members to support its activities.

The members of The National Coal Council are appointed by the Secretary of Energy for their knowledge, expertise and stature in their respective fields of endeavor. They reflect a wide geographic area of the United States (representing more than 30 states) and a broad spectrum of diverse interests from business, industry, and other groups, such as:

- ✓ Large and small coal producers;
- ✓ Coal users such as electric utilities and industrial users;
- ✓ Rail, waterways, and trucking industries s well as port authorities;
- ✓ Academia;
- ✓ Research organizations;
- ✓ Industrial equipment manufacturers;
- ✓ Environmental interests;
- ✓ State government, including governors, lieutenant governors, legislators, and public utility commissioners;
- ✓ Consumer groups, including special women's organizations;
- ✓ Consultants from scientific, technical, general business, and financial specialty areas;
- ✓ Attorneys;
- ✓ State and regional special interest groups; and
- ✓ Native American tribes.

The National Coal Council provides advice to the Secretary of Energy in the form of reports on subjects requested by the Secretary and at no cost to the Federal Government.

EXECUTIVE SUMMARY

The Secretary of Energy authorized this report by The National Coal Council (NCC). The report focuses on carbon dioxide sequestration opportunities and offers recommendations on needed research and development to bring cost-effective competitive sequestration technologies to the market. Scientists, policymakers and the public in general must recognize and deal with the continuing importance of coal, as well as other fossil fuels, as a major source of energy, especially electricity, even in a world constrained by concerns about human-induced climate change.

It is imperative that carbon dioxide sequestration and generation efficiency becomes high priorities if the goal is to manage carbon in the atmosphere while providing low-cost, reliable energy to drive the national as well as global economy. The NCC proposes a three-part management strategy to accomplish this task:

1. Maximize the efficient use of fossil fuels in order to minimize CO_2 emissions;
2. Shift to low-carbon and zero emissions technologies; and
3. Capture and sequester CO_2 emissions and that which is present in the atmosphere already.

In order to successfully implement this strategy, research is needed to verify the feasibility of the numerous carbon dioxide sequestration options available. Leadership, in the form of a partnership between industry and government, is needed in order to demonstrate these sequestration technologies on a large enough scale. Costs must be reduced so that these technologies can be effectively implemented.

Conclusions

Most independent experts in the field project that the demand for electricity will continue to increase in the United States and will increase even more worldwide. Therefore, The National Coal Council concludes that the United States will need to do the following and, to the extent possible, encourage other nations to do the same.

1. Actively promote the efficient use of energy and encourage research to improve the efficiency of end use technologies. This will minimize the amount of increased energy required with a minimal reduction in wealth.

2. Encourage the use o more efficient energy conversion technologies that minimize the impact on environment. This includes such technologies as those based on non-hydro renewable resources. Improvement in many of these technologies, based on further R&D, will be needed to make them economically useful.

3. Place a high priority on improving all coal conversion technologies to make them more efficient and to reduce environmental impacts. (Details of this strategy are covered more fully later in this report.) Even with development and deployment o other technologies and with improved efficiency in end use, there will be required in the U.S. the continued conversion of coal to electricity at reliable, cost-effective levels. It is generally recognized that in the rest of the world coal use will increase substantially, and improved conversion rates will protect the environment globally.

4. Develop technologies and applications to sequester CO_2. If CO_2 is to be managed effectively to achieve the total ambient levels now thought desirable – even with successful applications of energy efficiency technologies, increased use of renewable fuels and application of improved coal conversion technologies – further actions will have to be taken to sequester CO_2.

5. Fund substantial research and development on CO_2 management technologies. CO_2 removal and sequestration is possible in some no-generation technologies but is now

neither physically reliable nor economically feasible for electric generation combustion technologies. Therefore, given the current status of such technologies, there will be required a significant R&D effort. This subject comprises much of the bulk of this report.

Recommendations

The National Coal Council strongly recommends that the United States government, with the Department of Energy as the lead agency, implement an aggressive carbon management program than that which is currently underway. The major components should be research and development of cost-effective carbon dioxide sequestration technologies and efficient, super-clean, multi-use electric generation technologies. Specific recommendations are listed below:

Carbon Dioxide Separation and Capture: The Department should evaluate, improve and develop advanced chemical absorption solvents and physical adsorbents; develop improved membrane separation devices; conduct research to shorten the processing time and examine the handling demands of the silicate carbonation processes; develop additional technologies for transportation and storage of the produce upon successful completion of CO_2 separation and capture.

Geological CO_2 Sequestration. The Department should identify potential CO_2 storage options in saline reservoirs, rock caverns, unminable coal seams and salt domes. These sites should be characterized for their economic viability, and from the points of view of environmental protection.

Ocean CO_2 Sequestration: The Department should evaluate potential biological and chemical impacts on the oceans of CO_2 injection; develop the scientific ability to monitor biological, chemical and meteorological responses to ocean fertilization over long time periods and large distances in conjunction with other research organizations, including other Federal agencies, increase its research into iron fertilization in the ocean.

Terrestrial CO_2 Sequestration. The Department should refine the monitoring and verification methods for sequestering CO_2 in soil, vegetation, agricultural lands, pastures, tundra, forests and wetlands. Also, the long-term issues of the use of large tracts of land for carbon storage need resolution.

Advanced Concepts in CO_2 Management: The Department should increase research and development on the decarbonization of coal to produce hydrogen rich streams for electricity production and pure CO_2 for industrial use; conduct research based on biomimetic processes (i.e., processes that mimic the physics and chemistry of living systems) to fix CO_2.

Improved Generation Technologies: The Department should continue and if possible accelerate its work on achieving the success of super-clean, high efficiency, multi-use electric generation technologies, and more specifically, Vision 21; increase research into zero emissions technologies for coal.

Coproduction: The Department should accelerate research into the production of chemicals and clean transportation fuels from coal.

OVERVIEW

Just as nations require more energy than ever before, concerns about global climate change are prompting serious efforts to drastically reduce the use of fossil fuels.

Two billion – a third of the world's population – live without electricity. As economies grow in developing countries, the number of people plugging in lights, televisions, computes, telephones, refrigerators and microwave ovens will skyrocket.

Meanwhile, a surging economy and the explosion in communications – wireless phones, the Internet and all its associated devices – have combined to produce an extraordinary demand for electricity production in the United States. Years of low-cost gasoline have fueled a consumer rush to sport utility vehicles and a continued preference for private vehicles instead of public transportation.

Against this backdrop, the 1992 Framework Convention on Climate Change (FCCC) – the Rio Treaty – binds the United States and other developed nations to stabilize the atmospheric concentration of greenhouse gases at a level that does not affect the earth's climate system. Emissions from fossil fuels, the source of 85% of the world's energy, have become the biggest targets. Many have predicted that this could be the end of the fossil fuel industry. However, most independent experts in the energy field project that energy will continue to grow as economic growth progresses and that fossil fuels will remain the fuels of choice for economic reasons. This is true not only for the United States, but developing nations as well. Virtually every credible energy forecast predicts that burning fossil fuels, especially coal for use in generating electricity, will not only continue, but actually increase over the next 20 years and beyond. In fact, our future economic health depends on it.

In addition to its technology leadership, the United States has one major competitive advantage: economic, reliable energy; especially electricity. Coal fuels about 56% of electricity generation in the United States today. The new economy insists on both low cost and high reliability and thus relies heavily on coal-fired electric generation. The significant expense of replacing the lowest cost type of electricity generation today, coal-fired generation, would increase the price of electricity and fuel inflation. Capacity margins have been steadily declining over the last 10 years as the market responds to competition in the electricity industry. Without coal-fired generation, system reliability in the face of shrinking capacity reserves cannot be maintained. Reliability and power quality will become more important as the digital economy of the 21^{st} century grows.

Natural gas is expected to met nearly all of the growth in electricity demand in the United States over at least the next five-year period. However, supply chain limitations may limit the ability of the natural gas industry to continue to meet growing demands for electricity. Gas turbine delivery from the major manufacturers in some cases has been extended to 2003 if ordered today. In addition, pipeline capacity is constrained in the very regions where power plants must be developed.

Non-hydro renewable energy is also playing a small part in meting growth in demand. However, wind, solar and biomass projects cannot met the criteria of economic power. Costs are relatively high – especially if one includes the cost of storage devices for intermittent renewables like wind and solar – and will have to come down before non-hydro renewables can contribute more than a few percent of domestic generation.

How will coal meet the challenges of the new economy? It will meet them through the development and implementation of carbon dioxide sequestration technologies and through the development and implementation of more efficient, super-clean, multi-use electric generation technologies.

What is carbon dioxide sequestration? It is the capture and secure storage of CO_2 that otherwise either would be emitted to or is already present in the atmosphere. There are several current technologies available to do this, but none on a size or scale to make a major contribution to removing CO_2 from the global cycle. While there are several methods in the research stage that offer promise, much more work is necessary in order to bring them to the market.

The current major problem associated with most CO_2 sequestration technologies is cost. How swiftly CO_2 sequestration can be commercialized depends on the support given to research and development of these technologies in an effort to improve performance and decrease costs. There are many technological approaches for CO_2 sequestration. These development pathways must be prioritized to make effective use of limited funding. If prioritized currently, the development of innovative approaches to CO_2 sequestration will be accelerated through research and development.

To a limited extent CO_2 management is already available and relatively cost-effective through the management of soils and forests. While addressing CO_2 this way can counteract a portion of human-induced CO_2 (e.g., 10%), the potential or capturing CO_2 directly at the point of generation is much greater. While CO_2 sequestration at facilities like power plants is currently possible, it is extremely costly. Challenges exist regarding use or storage of the captured CO_2. If costs can be reduced, carbon management, anchored by CO_2 sequestration and efficiency improvements could allow our nation, and the rest of the world as well, to continue to benefit from a domestic, economic energy supply of coal, while concurrently addressing concerns about CO_2 emissions.

The Department of Energy has implemented research programs aimed at carbon management. The request for Fossil Energy Research and Development in the 2001 federal budget (FY-2001) is $384.6 million (including $9.0 million from prior year balances) the FY-2001 budget request includes $375.6 million in new money. This continues DOE investments in advanced technological concepts, such as the capture and sequestration of CO_2 and development of advanced, highly efficient, power generation and fuel producing technologies that together could reduce, or in some cases nearly eliminate, CO_2 emissions from fossil fuel facilities. <u>Development of these new technologies will help maintain strong economic growth while meting existing and new environmental goals.</u>

The portion of the Fossil Energy FY-2001 budget request to develop cleaner, more energy efficient coal and electric power generating technologies is $193.8 million, $18.7 million below last year’s budget. This must be increased in future yeas. The centerpiece of this program is DOE’s Vision 21 Energy Plant of the Future, a new concept that, coupled with CO_2 sequestration, could greatly reduce environmental concerns over the future use of fossil fuels. The goal of the Vision 21 program is to develop a set of advanced technology modules that could be configured into a new class of multi-product facilities for both central and distributed energy production in the 2010-2030 time frame. A total of $14.2 million is included in the current federal budget for Vision 21 development efforts.

The request also includes a major expansion of the Department’s exploratory research into carbon sequestration. DOE is requesting $19.5 million for carbon sequestration research in FY-2001, more than double the level for FY-200. An extraordinary private sector response to a recent department solicitation (more than 60 proposals with cost-sharing averaging greater than 40%) has shown that private industry is prepared to partner with DOE in pursuing this exciting future possibility for low-cost carbon sequestration.

CARBON SEQUESTRATION RESEARCH FUNDING

DOE Organization	**FY 1999 Appropriation**	**FY 2000 Appropriation**	**FY 2001 Request**
Science	**$6,753**	**$19,478**	**$23,132**
Fossil Energy	**5,949**	**9,182**	**19,500**
Total	**$12,702**	**$28,660**	**$42,632**

The National Coal Council strongly recommends that the United States government, led by the Department of Energy, in full cooperation with other agencies and in partnership with the entire coal industry, implement an event fuller and more aggressive carbon management program with a major component being research and development of cost-effective CO_2 sequestration technologies.

INTRODUCTION

In June 1992 the United States signed the United Nations Framework Convention on Climate Change (FCCC), otherwise known as the Rio Treaty. Later that year the United States Senate ratified that treaty, joining 160 other nations.

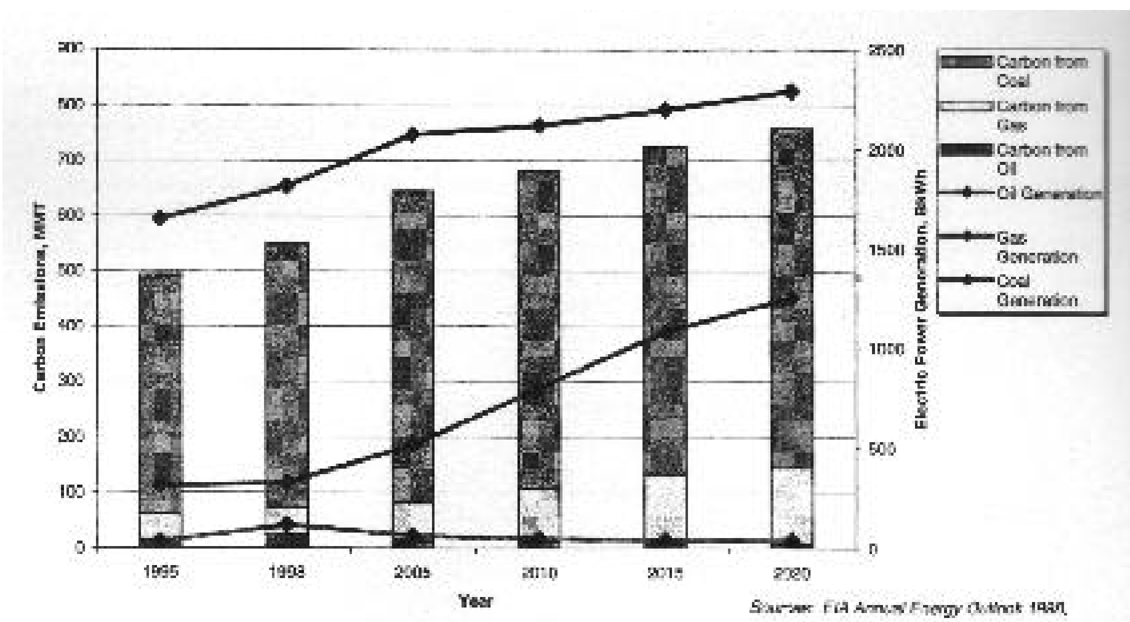
While recent attention has been focused on the as-yet ungratified Kyoto Protocol, ultimately the atmospheric concentration guidelines of the FCCC could require a much more stringent global carbon management strategy. This management strategy has three basic parts:

- Maximize the efficient use of the fossil fuels to minimize CO_2 emissions;
- Shift to low-carbon or zero-carbon technologies; and
- Capture and sequester both CO_2 emissions and CO_2 that is already present in the atmosphere.

In the context of this challenge, electricity remains the most practical means of accelerating the current trend of decarbonizing the energy systems of the world. As economies of developing nations grow, their electric and energy demands will skyrocket. Where will al of this electricity come from? According to the United States Energy Information Administration (EIA) **Annual Energy Outlook 2000**, it will come primarily from the increased use of fossil fuels, primarily coal and natural gas.

An additional demand on fossil fuels would occur if a significant portion of United States nuclear generation is retired over the next 20 years. Renewable generation would almost certainly not be able to make up the generation gap caused by nuclear retirements. An active CO_2 sequestration program will play an important role in maintaining fossil fuels as part of a robust generation portfolio.

U.S. Electric Power Generation and Carbon Emissions by Fuel, 1995-2020



It is imperative that increased generation efficiency and carbon dioxide sequestration become high priorities if the goal is to manage carbon dioxide in the atmosphere while providing low-cost energy to drive national and global economies.

This report, conducted at the request of the Secretary of Energy, focuses primarily on carbon dioxide sequestration opportunities and offers recommendations on needed research and development to bring cost-effective competitive sequestration technologies to the market.

CARBON DIOXIE SEQUESTRATION TECHNOLOGIES

This report builds on existing research underway by numerous experts, including DOE, and recommends major areas for additional research and development that will lead to implementation of carbon dioxide sequestration as a major tool in a global carbon management strategy.

Carbon dioxide (CO_2) sequestration is the capture and secure storage of CO_2 that would otherwise either be emitted to or is already in the atmosphere. There are several current technologies available to do this, but none on a size or scale to make a major contribution to removing CO_2 from the global carbon cycle. While there are several methods in the research stage that offer promise much more work is needed in order to bring them to the market. The following is a brief discussion of several of these types of technologies.

Carbon Dioxide Separation and Capture

It is produced in many industrial applications such as electric generation, steel making, cement production and so forth. It is also emitted by automobiles, other mobile sources, and dispersed sources, such as building heating. In short, any combustion of fossil fuels creates CO_2 as a by-product. This section of the report will focus on industrial and power plant CO_2 separation and capture only.

Several technologies exist to separate CO_2 from power plant and industrial flue gases. In one process CO_2 is absorbed by contact with various solvents and then released by steam heating of the solvent or by passing this liquid through activated carbon or special membranes. In another process, silicate rock is carbonated, capturing CO_2 in a stable, solid form for disposal. None of the current technologies has been used at the level needed for a large-scale carbon management strategy.

If the currently available separation and removal technologies were to be applied to a conventional coal-fired power plant, the cost of electricity from that plant would increase substantially. The amount of that price increase would depend on the plant characteristics, the type of membranes and filters used, and other plant operational data. Preliminary estimates for silicate carbonation are still being developed, but they do show the potential for a significantly lower process cost than solvent extraction. Price increase estimates for either technology in the increasingly competitive electricity industry are significant. To add CO_2 controls will approximately double the cost of electricity.

These costs must be dramatically reduced or offset in order to make this type of collection feasible. Technologies are needed to transform the captured CO_2 into a useable product or to dispose of CO_2 safely and cost-effectively. Concentrated, pure CO_2 is used in some industrial applications such as oil recovery, soft drinks, construction and food preservation and packaging, but these would use only a fraction of the CO_2 that would be produced by power plant capture. Moreover, some of these applications (food processing, for example) will ultimately lead to the release of CO_2 to the atmosphere. Early estimates for solid capture through silicate carbonation indicate a need for large amounts of bulk material handling. Potential uses for solid forms and need development.

Additional scientific and engineering research and development is needed in order to determine the physical efficiency and economic feasibility of current technologies in any carbon management strategy. Technology development needs include evaluation, improvement and development of chemical absorption solvents and physical adsorbents, membrane separation devices and testing at various levels in order to bring the technologies to scale. Silicate carbonation processes need further study and development to shorten processing time and examine material handling demands. Also, field testing at power plants is essential.

It must be noted that these types of technologies are suited primarily to power plant and industrial plant applications. To capture CO_2 emissions from dispersed sources such as transportation sources, apartment building, schools and commercial buildings offers a different set of challenges not well suited to these capture and separation technologies.

Once captured, additional technological challenges and associated costs will be incurred for transportation and storage.

Geological CO_2 Sequestration

Carbon dioxide sequestration in geological formations involves the injection of captured CO_2 into underground formations such as oil and natural gas fields, unminable coal seams, saline reservoirs and rock formations. Many oil operations currently inject CO_2 into wells to enhance recovery of the product. The technology is well understood for these operations. During 1998, the most recent data year, United States oil field operations pumped about 43 million tons of CO_2 into 70 wells in order to enhance product recovery.

While this amount is rather small compared to global CO_2 emissions, it indicates a huge potential for sequestration. There are far more potential candidates for this process than the 70 oil and gas wells currently using this technology. However, even greater opportunity for storage of large volumes of CO_2 injection are found in geologic formations. Saline reservoirs, rock caverns and salt domes located around the globe have the potential to sequester millions and possible billions of tons of CO_2.

Major research is needed to identify and characterize all of the potential sites. Technology must be developed to economically transport the CO_2 to these sites. The environment around these sites needs to be monitored to insure that the CO_2 remains sequestered. Public and government entities will need to be involved in this process, and, the whole process must be made economically viable.

Currently, geological CO_2 sequestration is being conducted in Norway. Sleipner offshore oil and natural gas field is in the middle of the North Sea, some 240 kilometers off the coast of Norway. Workers on one of the natural gas rigs there inject 20,000 tons of carbon dioxide each week into the pores of a sandstone layer 2,000 meters below the seabed. The injection at Sleipner began in October 1996 with incentives derived from imposed carbon taxes, it marked the first instance of CO_2 being stored in a geologic formation as a means of addressing climate considerations.

The natural gas reservoir at Sleipner is diluted with 9% carbon dioxide – too much for it to be attractive to customers, who generally accept no more than 2.5%. So, as is common practice at other natural gas fields around the world, anon-site chemical plant extracts the excess CO_2. At any other installation, this CO_2 would simply be released to the atmosphere. But the owners of the Sleipner field – Statoil, Exxon, Norsk Hydro and Elf – decided to sequester the greenhouse gas by first compressing it and then pumping it down a well into a 200-meter-thick sandstone layer, known as the Utsira Formation, which was originally filled with saltwater. The nearly one million tons of carbon dioxide sequestered at Sleipner last year may not seem large, but in the small country of Norway, it amounts to about 3% of total emissions of this greenhouse gas.

In other parts of the world, companies are planning similar projects. In the South China Sea, the Natuna field contains natural gas with nearly 71% carbon dioxide. Once this field has been developed commercially, the excess carbon dioxide will be sequestered. Other studies are investigating the possibility of storing captured carbon dioxide underground, including within liquefied natural gas installations at the Gorgon field on Australia's Northwest Shelf and the Snow White gas field in the Barents Sea of northern Norway, and in the oil fields of Alaska's North slope. Additional storage opportunities exist in deep, unminable coal seams where valuable methane can be produced as a by-product of CO_2 sequestration.

In all the projects now under way or in development, carbon dioxide is being captured for commercial reasons – for instance, to purify natural gas before it can be sold. The choice facing the companies involved is whether to release the greenhouse gas to the atmosphere or incur additional cost by storing it.

This is somewhat different from the capture and storage of CO_2 from power plants, for which both the capture and storage activities incur added costs.

Ocean CO_2 Sequestration

Experts predict that of the CO_2 emitted today and not sequestered, about 90% will be absorbed by the oceans by the year 2100. Currently two methods are under discussion for ocean CO_2 sequestration. Both methods require considerable research and development, but have the promise of dramatically reducing CO_2 concentrations. They are: 1) direct injection of captured CO_2 deep into the ocean, and 2) increasing the net natural CO_2 uptake of the ocean via the use of micronutrients in areas of the ocean where CO_2 could be absorbed by an increase in the growth of plankton.

The technology for pumping CO_2 into the ocean is not yet well-established. I is basically the reverse of pumping oil and natural gas out of the ground, there is much about the total process we do not fully understand.

Deep ocean injection is accomplished by capturing CO_2 and injecting it into the ocean as a supercritical fluid that remains on the ocean floor, or which could dissolve into deep ocean waters. It will form clathrates by reacting with the water over time. The primary concern is how the additional CO_2 could affect the acidity of the ocean. Changes in acidity can alter habitat and have an impact on the aquatic life in the vicinity of the injection. Keeping the concentration of CO_2 dilute may minimize this potential impact, but more biological research is needed. Although deep ocean injection may become a valuable strategy for long-term CO_2 storage, it is not well-suited for domestic applications, because the wide North American continental shelf means that nearly all potential storage sites are many hundred miles off shore.

The second oceanic storage concept is ocean fertilization as a means of accelerating the growth of the small plants that live in the ocean (phytoplankton). They are a natural source of CO_2 sequestration. These phytoplankton are at the bottom of the ocean's flood chain and are eaten by larger animals on up the food chain. It is estimated by experts in the field that 70-89% of the fixed carbon in the ocean's surface water is recycled in this manner. The remaining 20-30% settles to the deep ocean waters.

Some areas of the ocean near Antarctica contain all the necessary nutrients (except iron) to support a significant growth of plankton. Research in the past has demonstrated that natural iron fertilization significantly reduced CO_2 concentrations in the atmosphere.

Currently, the need exists to determine the potential ecological impacts of increased fertilization in the ocean. More research is needed to determine if there is an ideal rate of iron fertilization that will maximize the drawdown of CO_2 from the atmosphere while not harming the ocean environment. Changes could occur, both near-term and long-term, and possibly in locations distant from the fertilized area. Currents, wind patterns and migrating animals could all be affected and could also play a role in such impacts. Iron fertilization likely will succeed in some ocean environments which show growth characteristics that are similar to those found in coastal ecosystems.

There are significant gaps in our understanding of ocean fertilization. It is not clear that it will be benign, if used for high-volume CO_2 sequestration. Also, the scientific ability to monitor responses needs better development, especially for large-scale applications. This effort must include scientific confirmation that the technology is both safe and benign for the environment.

The promise of CO_2 sequestration in the ocean is great, but much work needs to be done to insure that such sequestration protects the oceanic environment and to secure public support for this technology. We need to better understand the current carbon cycle of the ocean so that we have a benchmark for measuring future changes. Biological and chemical research must be increased to determine what changes will occur as a habitat and as a weather-maker if these technologies are to gain public acceptance.

Terrestrial CO_2 Sequestration

The terrestrial ecosystem – basically one-quarter of the surface of the earth – functions as a huge "air purifier" for CO_2 removal. Vegetation sequesters CO_2 directly from the atmosphere, using it as a source of nutrition to foster growth and reproduction. Experts in the field estimate that the terrestrial ecosystem comprised of forests, agricultural lands, pastures, wetlands, tundra and soils sequesters a net amount of about 1.5-2.0 billion tons of carbon annually, excluding tropical deforestation. That is about one-quarter of the total annual global anthropogenic emissions of carbon. More can be done to enhance this situation.

Increasing the amount of forested and wetland areas and decreasing deforestation would be beneficial. CO_2 sequestration could be enhanced by improved agricultural practices in tilling, fertilization and other cultivation practices. Using trees to shade building would both sequester CO_2 and lower energy needs to cool buildings. CO_2 is also sequestered by producing long-lasting wood products via tree harvesting followed by replanting.

The technical potential for forest carbon management is large enough to offset a significant portion of anthropogenic contributions to CO_2 in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report projected that during 1995-2050, slowing deforestation, promoting natural forest regeneration and global reforestation could offset 220 to 320 billion tons of CO_2 (12-15%) of fossil-based CO_2 emissions. Three-quarters of this storage could be accomplished in the tropics. Other analyses suggest that even greater amounts of terrestrial CO_2 storage is possible.

The electric utility industry has recently initiated forestry projects specifically designed to conserve ecosystems and offset CO_2 emissions. The following are specific reasons for utilities to participate in forest carbon management include:

- There is a large technical potential for forest carbon management – a single project can offset millions of tons of CO_2 emissions.

- Forestry options to manage carbon are cost-effective in many cases (i.e., costing only a few dollars per ton of CO_2 offset). Forest carbon management opportunities can be among the most economical ways to address CO_2 emissions.

- Forestry carbon management adds flexibility, thus expanding the electric utility repertoire of options.

- Forestry options to manage CO_2 are well received by the public and most environmental groups.

- Forestry efforts have positive secondary environmental and social benefits (e.g., restoration of degraded lands and protection of biodiversity).

- International projects help to demonstrate the effectiveness of joint implementation activities with other nations, which is a critical tool for economically addressing climate change issues.

Illustrative of these efforts are the projects of the UtiliTree Carbon Company, a non-profit organization sponsored by 41 electric utilities in North America. UtiliTree's eight current projects represent a diverse mix of rural tree planting, forest preservation, forest management and research efforts at both domestic sites (Arkansas, Louisiana, Mississippi and Oregon) and international sites (Belize and Malaysia). UtiliTree has committed slightly over $2.5 million to fund this "pool" of projects. Carbon dioxide will be managed at a cost of about $1 per ton, including administrative expenses. Over two million tons of CO_2 benefit is estimated from the projects over their 40-70 year lifetimes. All projects include extensive external verification of benefits. Experts have determined through a series of technical workshops and projects that, for most types of forestry projects, carbon management benefits can be accurately quantified.

The low cost of forestry projects today relates to supply exceeding demand and uncertainty about rules and requirements. The cost could increase substantially after the best projects are funded, if there are stringent monitoring and verification requirements, and if the price increases due to growth in demand.

There are varying perceptions of forestry projects among policymakers. Critics postulate that forestry projects are more prone to leakage (when indirect and feedback effects outside project boundaries reduce net project benefits), that forestry projects are more prone to upset (e.g., due to natural disasters), or that forestry project benefits cannot be estimated accurately or verified. In reality, as concluded by international panels of experts at several workshops sponsored by government and private sectors entities: 1) these issues are not unique to forestry projects and often are no more of a challenge than for non-forestry projects; and 2) quantification of project-level benefits has been determined to be less of an analytical challenge than expected previously.

All of these issues will be addressed in a special report by the IPCC that will examine various legal, policy and technical issues related to the Kyoto Protocol's treatment of land use change and forestry activities. This special report, to be completed by June 2000, will address definitions of terms, accounting, monitoring and verification, and project-based accounting issues.

Terrestrial sequestration is recognized for its technical, economic and environmental potential in a carbon management strategy. Forest carbon management alone is estimated by experts in the field to have the capacity to store more than 10% of the CO_2 emitted to the atmosphere annually. However, more needs to be done in this area. Methods must be refined to monitor and verify how much carbon is being stored. Long-term issues of the use of large tracts of land must be addressed on the political, biological and geochemical levels.

Advanced Concepts in CO_2 Sequestration

Looking into the future, more innovative technologies will be needed for carbon management. Decarbonization of coal to produce hydrogen-rich streams and CO_2 for sequestration or utilization is one option. Decarbonization of coal and other carbonaceous fuels can be effected by partially converting these feedstocks to a synthesis gas, primarily carbon monoxide and hydrogen; by steam shifting the synthesis gas to primarily carbon dioxide and hydrogen; and by separating the carbon dioxide and compressing it to high pressure (e.g., 2200 psia) leaving a hydrogen rich gas, which can then be utilized for chemical synthesis, petroleum refining, power generation, or distributed for use in mobile or stationary fuel cells.

The high pressure CO_2 would then either be sequestered or utilized for chemical synthesis of fuels, (e.g., methanol or chemicals). These approaches would actually "recycle" CO_2 and utilize it for synthesis purposes.

An alternative approach is based on adapting the physical and chemical principles used by living systems to fix CO_2. This process is known as biomimesis, and it has the potential for capturing CO_2 at ambient temperature and pressure, simply by bubbling flue gas through a tank containing calcium ion and an enzymatic catalyst. The process yields calcium carbonate in a slurry form, which can be landfilled. Work on this approach is at a very preliminary stage, but laboratory tests are producing promising results. Artificial photosynthesis is another biomimetic approach for CO_2 fixation under the ambient conditions. Research to improve efficiency and reduce costs is clearly needed, but these and other innovative concepts can play an important role in CO_2 capture and sequestration.

The impact of high temperature anaerobic conditions and inputs of blends of CO_2 coal and biomass upon the char output of some thermo-chemical systems is yet another innovative approach to carbon sequestration which also warrants study. The possibility of reversing the geological clock by converting low rank coals back o more valuable peat (with the help of biomass) while sequestering CO_2 seems plausible. Such peat could contain valuable solid or liquid humic acids and humate soil and water amendments (soil organic carbon (SOC), activated charcoal, chelating agents, detoxifiers, etc.). The use of

SOCs to enhance the soil productivity of agriculturally depleted lands would contribute additional terrestrial sequestering of CO_2 in the form of enhanced plant growth.

Nature produces humic substances by weathering lignite to leonardite. For millennia organic farmers have transformed biomass to humus by composting. In recent years coal has been transformed to humic substances by chemical and biochemical processes. Carbon dioxide can be an oxidizer at high temperatures and can be strongly absorbed by coal char loaded with potassium. This sequestering technology should be advanced by pushing the frontiers of fuel blending, high temperature chemistry, catalysis and number of other neglected applied research areas this sequestering possibility should be advanced. The effort would have a number of pay-offs even if peat yields are insufficient.

One potential biological system which shows promise of achieving high photosynthetic efficiency is cultivated micro algal species such as T. suecica. If CO_2 in flue gases is used to stimulate growth, necessary nutrients are supplied, and short cultivation periods are utilized, very high carbon fixation rates per unit area may be achieved. This approach might be utilized to recycle a portion or all of the CO_2 being emitted by a typical coal-fired power plant.

Another terrestrial biological CO_2 fixation system produces halophytes, a salt tolerant species of plants which may be grown in semi arid regions.

Advanced CO_2 sequestration processes include formation of CO_2 hydrates for direct sequestration in terrestrial aquifers or the deep ocean, or alternately formation of CO_2 hydrates in the ocean from high pressure CO_2.

All of these areas require extensive process evaluation, fundamental research, and development in order to assess their potential in mitigating CO_2 concentrations in the atmosphere and minimizing global climate changes.

Another advanced concept in sequestration, broadly speaking, is development of low-cost biomass fuel, primarily for transportation application. Development and deployment of advanced biotechnology has many economic and international security advantages, not the least of which is substantial reduction of CO_2 emissions from the transportation sector.

And finally, a consortium of companies have recently formed an organization called the Zero Emission Alliance with the goal of supporting research into a process that promises a potentially emission-free, efficient conversion of coal to electricity. The combination of an anaerobic coal gasifier, a calciner, silicate CO_2 sequestration, and a solid oxide fuel cell provide the basic building blocks for the technology. Further research on this process will establish its ability as a tool for managing carbon.

Biological agents are being tested to see if, by metabolizing coal, they can produce sufficient energy and other commercial products to make their application economical.

These and other advanced concepts are candidates for funding as part of the longer-term program to develop a robust portfolio of sequestration options.

IMPROVED COAL-BASED GENERATION TECHNOLOGIES: IMPROVING EFFICIENCY AND REDUCING EMISSIONS

During the last two decades, significant advances have been made in the reduction of emissions from coal-fired electric generating plants. New technologies include better understanding of the fundamentals of the formation and destruction of criteria pollutants in combustion processes (low NO_x burners) and improved methods for separating criteria pollutants from stack gases (FGD systems), as well as efficiency improvements in power plants (clean coal technologies). Future demand for more environmentally benign electric power, however, will lead to even more stringent controls of pollutants (SO_2 and NO_x) and greenhouse gases such as CO_2.

To continue to use coal it will be necessary to develop advanced coal-based technologies which will be able to generate electricity at significantly higher efficiency (in the range of 50% and above) than existing plants (in the range of 33-36%). These technologies must be commercially available in the United States soon, as it will be necessary to replace older power generating plants beginning in 2010.

But the energy research and development programs underway in the United States, taken as a whole, are not commensurate in scope and scale with the energy challenges and opportunities the twenty-first century will present. This situation will be exacerbated by declining private sector contributions to energy research in the wake of ongoing industry restructuring.

Efficiency improvements alone may be able to significantly reduce CO_2 emissions in comparison to existing plants. However, it is estimated that even new, higher efficiency plants featuring new technologies may not be sufficient to comply with the FCCC emissions requirements. Therefore, emerging technologies related to CO_2 capture and sequestration must be a high priority.

In the near-term (2005-2020), there are several options for environmentally-favorable electric power generation, including the following technologies:

- Pulverized Coal (PC) in ultra-supercritical steam boilers (4500 PSI/1200 F) currently seems to be the system with lowest cost of electricity and capital costs, yet still provides considerable efficiency improvement over existing technologies (40-41% vs. 33-36%). Ultra-supercritical pulverized coal technologies can achieve an almost 20% reduction in CO_2 emissions for the same amount of energy generation from existing plants.

- The Pressurized Fluidized Bed Combustion (PFBC) technology with a topping combustor can reach 45% plant efficiency by 2010, and thus can reduce CO_2 emissions by about 33% in comparison to current electric generation technologies.

- Integrated Coal Gasification Combined Cycle (IGCC) power plants can achieve an impressive 47% efficiency by 2010 and may possibly reach even higher efficiencies by 2020 when advanced hot gas cleanup systems should be commercially available. Such systems can reduce CO2 emissions by 40% over current commercial technologies.

- The Zero Emissions Coal process pioneered by groups from Lo Alamos National Laboratory working under DOE's Vision 21 program anticipates the doubling of coal to electricity conversion efficiency. An anaerobic gasifier utilizing CO_2 acceptor technology produces hydrogen from a coal water slurry and calcium oxide. Hydrogen is converted to electricity via a solid oxide fuel cell and the gasifier's other product, calcium carbonate, is calcined, producing calcium oxide for the gasifier and a pure stream of CO_2 for sequestration. This stream is sequestered as a solid carbonate through carbonation of natural silicates under initial proposed processes. The elegance of the concept lies in its use of waste heat generated by the carbonation, gasification, and fuel cell to drive calcinations, thus achieving excellent thermodynamic efficiencies. Ideally, the process can achieve highly efficient electricity production without any emissions whatsoever, since combustion and gaseous forms are eliminated.

- Fuel cells powered by coal-derived synthesis gas can increase the efficiency of gasification technology to greater than 70% if equipped with a gas turbine bottoming cycle.

- Vision 21 modules which produce transportation fuels and value-added chemicals in combination with advanced power generation technologies will enhance the overall plant efficiency and promote greater deployment of carbon dioxide capture systems.

Assuming that these relatively near-term options should prove by themselves unable to offer CO_2 reductions sufficient to adequately address the climate change issue, adding the capture and sequestration of CO_2 will help achieve sustainable energy systems over the long-term.

There are currently two possible approaches to optimizing coal-based generation for retrofits of CO_2 capture technology:

1) combustion with oxygen instead of air; and
2) gasification

In the modified combustion process, the combustion air is replaced by oxygen, thereby avoiding the large volume of nitrogen normally present in the stack gases. The combustion products are recirculated to the burner, which reduces the flame temperature to manageable levels in the boiler/combustor, and increases CO_2 concentrations in the stack gases to well about 90%. At this point, capture of CO_2 for eventual sequestration would become much less costly.

In one gasification process, high-pressure synthesis gas, consisting mainly of hydrogen (H_2) and carbon monoxide (CO), is produced in the oxygen-blown coal gasifier. CO_2 can be efficiently cleaned pre-combustion from shifted synthesis gas because of the high partial pressure of CO_2 in the gas.

Tables 1 through 3 summarize the performance targets, environmental goals, and cost and performance goals for all coal-based technologies that are currently being pursued. Figure 1 shows CO_2 emission rates from these technologies in comparison to that of state-of-the-art natural gas combined cycle generation.

Table 1
Performance Targets for Coal-Based Technologies

Performance Target	Today	2010	2020
Capital Cost, 1999 $/kW	**1000-1300**	**800-900**	**800-1100**
Efficiency, %HHV	**40**	**45**	**50-60**
SO_2 removal %	**95-99**	**99**	**99+**
NO_x lbs/mmbtu	**0.06-0.1**	**0.05**	**<0.05**
HAPS (hazardous air pollutants)	**Define goals**	**Meet goals**	**Meet goals**
Waste Utilization %	**15-30**	**50-75**	**100**
Overall Emissions		**Significant Reductions From Today's Technology**	**De Minimis Emissions**

Courtesy: Coal Utilization Research Council

Table 2
Environmental Goal for Coal-Based Technologies

Technology	Performance Parameter	Today	2010	2020	Beyond 2020
Pulverized Coal	**SO_2 Removal % NOx lbs/mmbtu Hazardous Air Pollutants Waste Utilization % CO_2 Capture %**	**98 0.1 define goals 15-30 0**	**99 0.05 meet goals 50-75 0**	**99+ <0.05 meet goals 100 0**	**N/A**
Pressurized Fluidized Bed Combustion	**SO_2 Removal % NO_x lbs/mmbtu Hazardous Air Pollutants Waste Utilization % CO_2 Capture %**	**95 0.1 define goals 15-30 0**	**98 0.05 meet goals 50-75 0**	**99 <0.05 meet goals 100 0**	**99 <0.05 meet goals 100 90**
Integrated Gasification Combined Cycle	**SO_2 Removal % NO_x lbs/mmbtu Hazardous Air Pollutants Waste Utilization % CO_2 Capture %**	**99+ (cold) 0.06 define goals 30 0**	**99+ (hot) <0.05 meet goals 75 0**	**99+ (hot) 0.01 meet goals 100 0**	**99+ (hot) 0.01 meet goals 100 90**
Integrated Gasification Fuel Cell	**SO_2 Removal % NO_x lbs/mmbtu Hazardous Air Pollutants Waste Utilization % CO_2 Capture %**	**N/A**	**N/A**	**99.99 0.01 meet goals 100 0**	**99.99 0.01 meet goals 100 90**

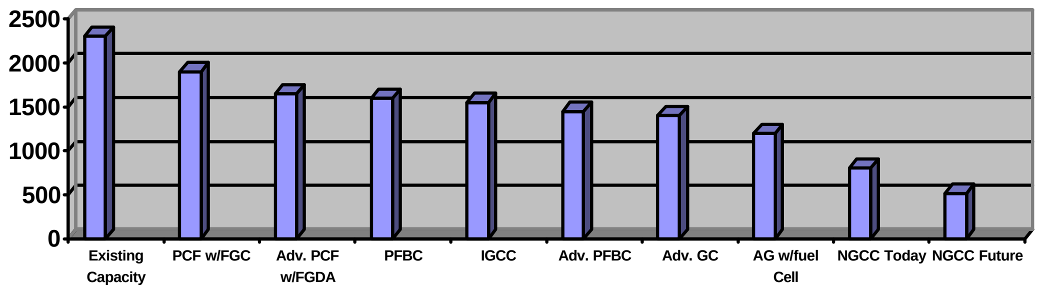
Courtesy: Coal Utilization Research Council

Table 3
Coast & Performance Goals for Coal-Based Technologies
(Fully Mature Plants in 1999 $)

Technology	Performance Parameter	Today	2010	2020	Beyond 2020
Pulverized Coal	**Capital Cost, $/kW Efficiency, % HHV Eqv. Availability, % CO_2 Capture**	**1000-1100 37-40 92 No**	**800-900 41-43 92 No**	**<800 43-45 92 No**	**N/A**
Pressurized Fluidized Bed Combustion	**Capital Cost, $/kW Efficiency, % HHV CO_2 Capture**	**1200-1300 40 No**	**800-900 45 No**	**800 45-50 No**	**1000+ 45+ Yes**
Integrated Gasification Combined Cycle	**Capital Cost, $/kW Efficiency, % HHV CO_2 Capture**	**1300-1400 42+ No**	**1000-1100 45 No**	**900 50-55 No**	**1100+ 50+ Yes**
Integrated Gasification Fuel Cycle	**Capital Cost, $/kW Efficiency, % HHV CO_2 Capture**	**N/A**	**N/A**	**1100 60-65 No**	**1200+ 60+ Yes**

Courtesy: Coal Utilization Research Council

Figure 1
Electric Power Technologies and Carbon Dioxide Emissions Rates
Courtesy: American Electric Power Service Corporation



The CO_2 capture and sequestration technology that is currently being used by commercial plants to produce CO_2 for enhanced oil recovery or to reduce CO_2 concentration in North Sea natural gas is based on chemical absorption with monoethanolmine (MEA). This process is expensive and its application requires large amounts of steam with resulting large efficiency penalties. The high expenses are mainly due to the low partial pressure of the CO_2 in the gases to be cleaned, while the power penalty largely results from the steam requirements associated with recycling the MEA.

The assessment for the near-term and mid-term technologies is made more difficult by the uncertainty of the time when enabling technologies such as reduced-cost oxygen production, hot gas cleanup, or less expensive gas separation will be available. For the long-term technologies, important variables include the development of cost-effective fuel cells as envisioned in the DOE's Vision 21 program.

Recommended technology policy actions include:

- Providing increased R&D funding for a portfolio of long-term energy technologies to maintain economically viable electric energy options for a potentially carbon-constrained future.

- Assuring that DOE maintains a balanced research program that includes both CO_2 capture and sequestration and advanced high efficiency power generation technologies. This approach will provide a robust portfolio of technology options to address unpredictable development in environmental regulations, policy decisions, and technology.

- Working to strengthen DOE's role in the development of environmental and global climate change policies and responses, relying on sound science, pragmatism, economic viability, and consistency.

The research, development, demonstration, and deployment of advanced coal-based energy technologies will help continue to provide low-cost, reliable, and environmentally sustainable energy. Work toward this end should build upon the successes of the DOE Clean Coal Technology Program and become a task of highest priority for the government, technology developers, manufacturers, and electric utilities.

GLOBAL PERSPECTIVE ON CO_2 SEQUESTRATION

Coal will continue to be the backbone of global electricity generation well into the 21st century. It is a vast resource in key markets as diverse as Australia, China, and India, in addition to the U.S. – countries with strong economic and security incentives to use their indigenous resources. Even Canada, which currently uses coal for only 17% of electricity generation, is highly dependent on coal in some regions of the country. An example is the province of Alberta, which relies on coal for 89-90% of its electricity. Continued use of coal over at least the next several decades will be critical to the continued economic health of coal-reliant economies.

The regional dependence of coal usage can be illustrated by noting that in the year 2050, North America, China, and South Asia are projected to account for 46% of electricity consumption, but 74% of global coal usage. (Data from World Energy Council and International Institute for Applied Systems Analysis, "Global Energy Perspectives to 2050 and Beyond, 1998"). Fortunately, even though coal use varies widely on a regional basis, carbon management strategies can be applied throughout the globe, wherever they are most cost-effective.

Sequestration will play an important role in the global management of carbon. Allowing flexibility in where and when emission reductions are made can dramatically reduce the cost of stabilizing atmospheric concentrations of greenhouse gases. The cost of CO_2 capture and sequestration, in particular, will vary dramatically over the regions of the world. The notion that making emission reductions wherever it is most economic is well accepted scientifically and can reduce the cost of achieving a specified atmospheric concentration by over 50%. Allowing flexibility in timing of the implementation of CO_2 sequestration technologies can reduce that cost much further while yielding the same ultimate atmospheric concentration.

POTENTIAL FOR SUCCESS

A carbon management program can achieve success without question, but active government support is absolutely necessary. A carbon management program, focused on CO_2 sequestration and generation efficiency improvements, must be supported just as aggressively as the flue gas desulfurization (SO_2 scrubber) program was supported in the early 1970s and the Clean Coal Technology Program in the 1980s and early 1990s. A weak, indifferent and piecemeal approach is a recipe for failure.

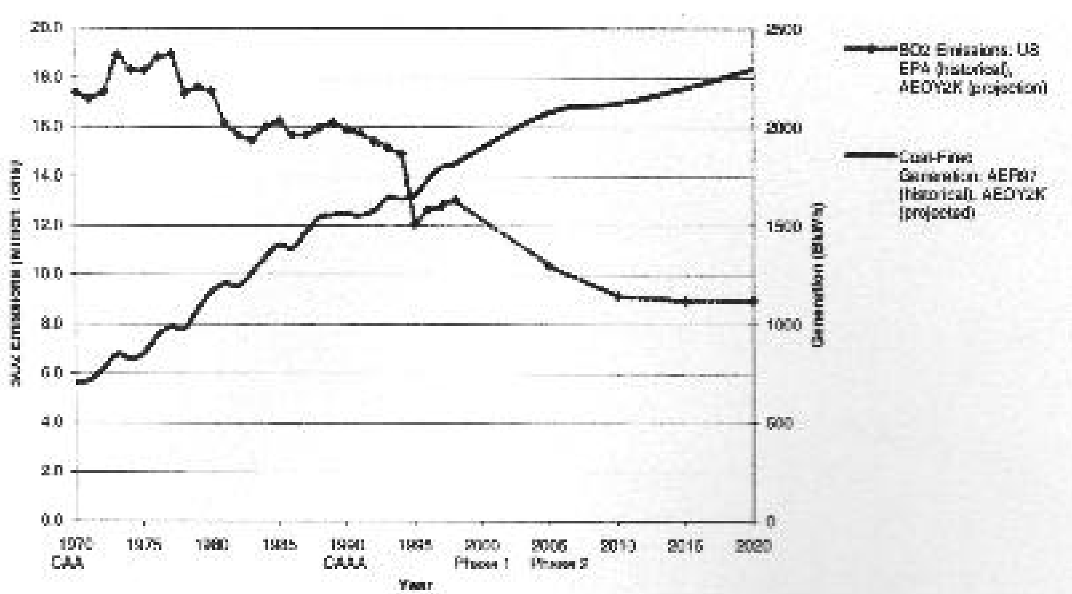
A look back over the past 30 years show what can be achieved when government, in partnership with private industry, leads in the research and development of technology.

Emissions of sulfur dioxide, nitrogen oxides and particulate matter, primarily from the electric utility industry have declined substantially over that time, despite increased generation to meet the nation's growing demand for electricity. As a result of these and other emissions reductions, the nation's air quality has improved significantly. Since 1980, despite a 36%. Increase in electricity generation and more than a 50% increase in coal use, electric utility SO_2 and NO_x emissions have declined significantly. Utility SO_2 emissions will be reduced almost 50% from 1980 levels (about nine million tons) before 2010. This will occur at a time when generation from coal is projected to increase by 200% (1,200 billion kWh in 1980 to over 2,200 billion kWh in 2010).

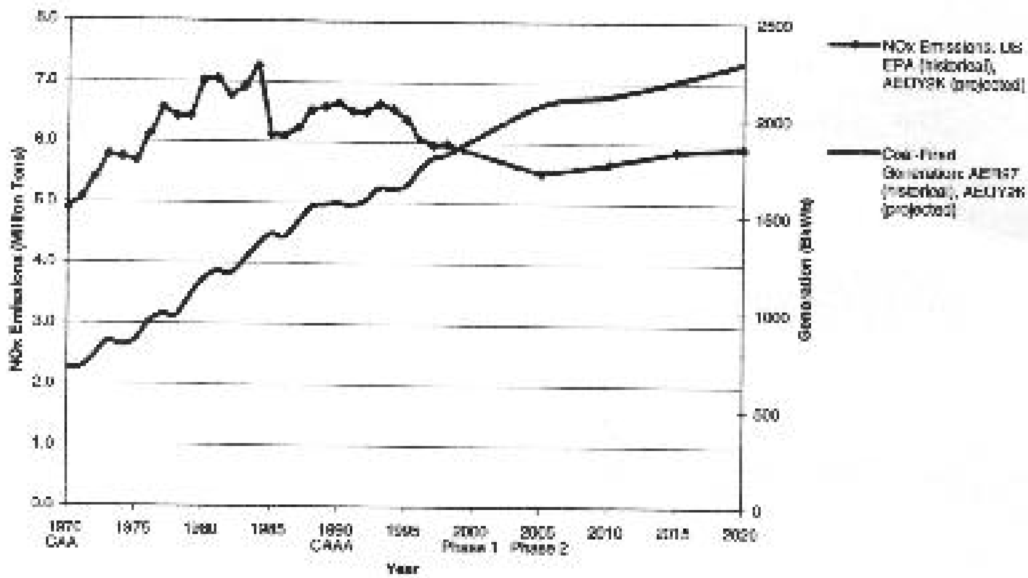
Nationwide, utility NO_2 has been reduced more than 2 million tons (about 30%) due to the acid rain program (Title IV) of the 1990 Clean Air Act Amendments. Further reductions in the eastern United States are expected in a few years under the EPA NO_x "SIP call." As of 1997, electric utilities emitted only 26% of national NO_2 emissions and less than 1% of national volatile organic compound (VOC) emissions. These are the two chemicals which man contributes to the formation of ground-level ozone.

This success had many drivers, but it would have been far more difficult to achieve and would have come later and at a much higher cost were it not for the government-led research and development of control technologies. These efforts continue to insure success into the first two decades of the 21st century, as shown by the following charts from the EIA **Annual Energy Outlook 2000**.

U.S. Coal-Fired Electric Power Generation and SO_2 Emissions, 1970-2020



U.S. Coal-Fired Electric Power Generation and NO_x Emissions, 1970-2020



The same type of leadership commitment is needed in the carbon management field. The National Coal Council sands ready to work with the Department of Energy in a full partnership to establish a positive, successful carbon management program.

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APPENDIX A

Description of The National Coal Council

Recognizing the valuable contribution of the industry advice provided over the years to the Executive Branch by the National Petroleum Council and the extremely critical importance of the role of coal to America and the world's energy mix for the future, the idea of a similar advisory group for the coal industry was put forward in 1984 by the White House Conference on Coal. The opportunity for the coal industry to have an objective window into the Executive Branch drew overwhelming support.

In the fall of 1984, The National Coal Council was chartered; and in April 1985, the Council became fully operational. This action was based on the conviction that such an industry advisory council could make a vital contribution to America's energy security by providing information that could help shape policies relative to the use of coal in an environmentally sound manner which, in turn, could lead to decreased dependence on other, less abundant, more costly, and less secure sources of energy.

The National Coal Council is chartered by the Secretary of Energy under the Federal Advisory Committee Act. The purpose of the Council is solely to advise, inform, and make recommendations to the Secretary of Energy with respect to any matter relating to coal or the coal industry about which the Secretary may request its expertise.

Members of The National Coal Council are appointed by the Secretary of Energy ad represent all segments of coal interests and all geographical regions. The National Coal Council is headed by a Chairman and a Vice Chairman who are elected by the Council.

The Council is supported entirely by voluntary contributions from its members. It receives no funds whatsoever from he Federal government. In reality, by conducting studies at no cost which otherwise might have to be conducted by the Department, it saves money for the government.

The National Coal Council does not engage in any of the usual trade association activities. It specifically does not engage in lobbying efforts. The Council does not represent any one segment of the coal or coal-related industry or the views of any one particular part of the country. It is, instead, to be a broad, objective advisory group whose approach is national in scope.

Matters which the Secretary of Energy would like to have considered by the Council are submitted as a request in the form of a letter outlining the nature and scope of the requested study. The first major studies undertaken by The National Coal Council at the request of the Secretary of Energy were presented to the Secretary in the summer of 1986, barely one year after the startup of the Council.

APPENDIX B

The National Coal Council – 2000 Member Roster
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Ernesto Corte, President & CEO, Gamma-Metrics, San Diego, CO

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APPENDIX C

National Coal Council – CO_2 Study Work Group – Year 2000

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The Secretary of Energy
Washington, DC 20585

May 5, 1999

Dr. E Linn Draper, Jr.
Chairman
National Coal Council
P.O. Box 17370
Arlington, Virginia 22216

Dear Dr. Draper:

Thank you for your letter summarizing the meeting of the National Coal Council that was held on November 19, 1998. I regret that my schedule did not allow me to join you, but I am pleased that you had a fruitful and productive meeting.

Over the past year, the Department has undertaken a major effort to ensure that our research and development programs are balanced and that our Federal investments are appropriately coordinated with industry. To do this, we are instituting a new portfolio approach to managing our R&D activities. This entails building a comprehensive stand-alone document that, for the first time will provide, in one place, a clear description of our entire $7 billion research portfolio.

We intend to use this document (l) as a means of explaining our current R&D activities and showcasing recent accomplishments, (2) as a basis for evaluating how balanced our portfolio is for the long term pursuit of our strategic goals, (3) to better align our technology investments with broader policy goals; and (4) as a tool for helping to plan for future investments through technology roadmapping.

The second part of this effort entails the development and use of technology roadmaps. By developing and using technology roadmaps, we seek to make clearer our R&D requirements and to improve strategic planning by better identifying priorities and aligning them with the best performers and available financial resources. The role of industry in these efforts--and I might add the enormous opportunity--is particularly important in various areas.

Carbon sequestration is one such area that we are working on and where industry involvement is particularly important. Thus, your suggested topic for a study on technologies to capture and sequester greenhouse gases is both timely and a worthwhile subject on which the Department needs industry input. I am pleased to grant approval to the Council to conduct this study.

I value the efforts of the Council and look forward to being with you at your upcoming meeting on May 18, 1999.

Yours sincerely,

Bill Richardson

Bill Richardson

APPENDIX E

CP&L Comments on The National Coal Council Report Titled "Carbon Management Research and Development Requirements"

Recommendations

The order of the recommendations seems to reflect the priorities of the research community, which does not necessarily agree with those of the electric industry. The emphasis of the proposed list appears to be on CO_2 extraction and storage by geological means. While this makes for interesting research projects, the costs of these technologies might lead our industry to put a higher priority on research to develop improved generation technologies with lower CO_2 emissions and refinement of cost-effective terrestrial sequestration. We propose a revised order of the recommendations to be:

- Improved Generation Technologies
- Pulverized coal
- Pressurized fluidized bed combustion
- Integrated coal gasification combined cycle
- Fuels cells
- Improved sequestration technologies
- Terrestrial sequestration
- Carbon dioxide separation and capture
- Geological sequestration
- Ocean sequestration

Carbon Sequestration

The technologies discussed within this section should include estimates of $/ton sequestered and the cost drivers.

Carbon Dioxide Separation and Capture

One of the major costs of this aspect of sequestration is the cost to compress the CO_2 to liquefy it for efficient handling. This is a major hurdle for all of the non-terrestrial sequestration techniques. Perhaps this should be discussed.

Advanced Concepts in Sequestration

This might be more appropriate titled "Advanced Concepts in Carbon Management" since it includes other aspects of carbon management besides sequestration.

Improved Generation Technology

This section does not seem to flow with the rest of the report. We suggest organizing it as shown above and reducing some of the general discussion.

Conclusion

The first paragraph of this section should be the last. It should be the last thing read.

Subj: "Sequestration" study

Date: 5/4/00 7:1955 PM Eastern Daylight Time
From: mllake@apsci.com (Max L. Lake)

To: rabeck@nationalcoalcouncil.org (Robert A. Beck)

Bob,
Relative to two of the proposed changes in the language of the report, I would like to bring attention to the change in title, and also the focus of the report as redirected by proposed broad identification of CO_2 emission from transportation and other sources.

With respect to the change in title, I do not challenge the accuracy of the proposed name change, but it is my understanding that these recommendations are directed to a larger existing DOE program which bears the name "Carbon Sequestration". It is important to retain the identity of the recommendations offered in the report intended to modify this program. In addition, I am concerned further migration from the original naming of the report could lead to "Research and Development Needs for CO_2 Sequestration." The proposed recommendations, all of which are directed at reducing the emission of CO_2 into the atmosphere, do not pertain exclusively to development of technology to capture CO_2 from the atmosphere, but to a portfolio of technologies which also include cleaner combustion methods as well as chemical reduction methods for coal refining. Any perceived focus on CO_2 sequestration exclusively, implies a shift of emphasis from CO_2 generation to effort to recapture and store CO_2 subsequent to generation. The title as proposed is certainly ac acceptable descriptive title. Changing the name runs the risk of implying a call for new programs rather than modification of the current DOE program, and cavalier modification, for example as hypothesized above, could undermine the collective goal of the recommendations.

With respect to commentary on other sources of atmospheric CO_2, this is only germane with respect to how proposed technology development will have positive outcomes from these sources also. The business of the National Coal Council should be to pro-actively address problems attendant to coal utilization. Any language construed to be directed to fixing blame elsewhere detracts from the mission of the Council and the credibility of the report.

I was pleased with the language of the last recommendation. The current heavy reliance on coal as a fuel for electric power generation represents a significant source of CO_2 in the atmosphere, and furthermore represents an inefficient chemical process for utilizing a major natural resource. As discussed in the meeting, research is needed to exploit the chemical assets represented by coal by developing more sophisticated chemical processing of coal – to generate clean sources of fuel, while exploiting other products available from coal processing, thereby creating a coal-based analog to the petrochemical industry.

I am looking forward to reviewing the "Final Draft" of the report.

Best regards,

Max

APPENDIX F
Acknowledgements

The members of the Working Group wish to acknowledge, with sincere thanks, the special assistance received from the following persons in connection with various phrases of the development of this report:

Pamela A. Martin, The National Coal Council

Editorial Consultant: Ms. Julie Clendenin