Hearing on

**Clean Coal Technology – Science, technology, and Innovation**

United States Senate Committee on Commerce, Science, and Transportation

27th April 2007

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Written Testimony

Senator Kerry and Members of the committee, good morning and thank you for the opportunity to address you on this important topic. My name is Gregory McRae and I am a professor of chemical engineering at the Massachusetts Institute of Technology. In addition to my research and teaching on energy and environmental issues I am also one of the co-authors of the recent MIT Report called the *Future of Coal – Options for a Carbon Constrained World* [1]. This study involved eleven colleagues from various disciplines at MIT as well as an external advisory group that represented diverse perspectives on the problem. This morning I would like to draw your attention to a few of the key recommendations from the report related to clean coal technology.

Four key premises drove our study:

1. There is a pressing need to address the global warming problem. The risks are real and the United States and other governments should take action to restrict the emissions of carbon dioxide ($CO_2$) and other greenhouse gases (GHG). [1,2].

2. Our second and equally important premise is that coal will continue to play a large and indispensable role in a greenhouse gas constrained world because it is cheap, abundant, and in the short term one of the fuel sources that can meet, at scale, the growing demands for electricity.

3. We believe that $CO_2$ capture and sequestration (CCS) are the critical enabling technologies that would significantly reduce $CO_2$ emissions associated with coal combustion. Much of the needed technology exists ($CO_2$ capture, transport and storage) but there is a critical need for several large scale demonstration projects to give policy makers and the public confidence that a practical carbon mitigation control option exits.

4. A key conclusion based on experience in other RD&D programs is that the government should not pick a "technology winner" per se, but rather create an environment that will enable the development of a diverse range of cost effective options to reduce green house gas emissions.

These and other issues are discussed in much more detail in [1]. In this morning's testimony I will focus on two key technical recommendations related to the future use of coal.

## The Driving Force for Change

The risk of adverse climate change from global warming is serious forced in part by growing greenhouse gas emissions. While projections vary, there is now wide acceptance among the scientific community that global warming is occurring, that the human contribution is important, and that the effects may impose significant costs on the world economy. As a result, governments are likely to adopt carbon mitigation policies that will restrict $CO_2$ emissions; many developed countries have taken the first steps in this direction. For such carbon control policies to work efficiently, national economies will need to have many options available for reducing greenhouse gas emissions. *The Future of Coal* [1] addresses one option, the continuing use of coal with reduced $CO_2$ emissions.

Coal is an especially crucial fuel in this uncertain world of future constraint on $CO_2$ emissions. Because coal is abundant and relatively cheap ($1–2 per million Btu, compared to $ 6–12 per million Btu for natural gas and oil) — it is often the fuel of choice for electricity generation, and perhaps for extensive synthetic liquids production in the future in many parts of the world. Its low cost and wide availability make it especially attractive in major developing economies for meeting their pressing energy needs. On the other hand, coal faces significant environmental challenges in mining, air pollution (including both criteria pollutants and mercury) and importantly, emissions of carbon dioxide ($CO_2$). Indeed coal is the largest contributor to global $CO_2$ emissions from energy use (41%), and its share is projected to increase.

The U.S. has 27% of the total global recoverable coal reserves, enough for about 250 years at current consumption. Over 50% of U.S. electricity was generated from coal last year. It is important to understand the magnitude of $CO_2$ emissions associated with power generation. A single 1000 $MW_e$ coal-based power plant emits between 5 and 8 million tonnes of $CO_2$ per year. A few statistics give a sense of the enormity of the challenge [4].

- There are the equivalent of more than five hundred 500 megawatt, coal-fired power plants in the United States with an average age of 35 years.
- China is currently constructing the equivalent of two 500 megawatt, coal-fired power plants per week, a capacity comparable to the entire UK power grid each year.
- At present the largest sequestration project is injecting one million tons/year of carbon dioxide ($CO_2$) from the Sleipner gas field into a saline aquifer under the North Sea.

By mid-century, given the expectation that coal use will grow substantially, the annual sequestration of several gigatonnes of carbon dioxide is the scale needed for a major impact on climate change mitigation,. This translates into sequestration of the $CO_2$ emissions from many hundreds of utility scale plants worldwide. Each plant will need to capture millions of metric tonnes of $CO_2$ each year. Over a fifty-year lifetime, one such plant would inject about a billion barrels of compressed $CO_2$ for sequestration [5,6].

## Recommendation 1 – Large Scale Demonstration of Carbon Dioxide Capture and Storage (CCS)

Carbon dioxide capture and sequestration (CCS) is the critical enabling technology that would reduce $CO_2$ emissions significantly, while also allowing coal to meet the world's pressing energy needs. What is needed is a successful large-scale demonstration of the technical, economic, and environmental performance of the technologies that make up all of the major components of a large-scale integrated CCS system – capture, transportation, and storage.

We have confidence that megatonne scale injection at multiple well-characterized sites can start safely now, but an extensive program is needed to establish public confidence in the practical operation of large scale sequestration facilities over extended periods, and to demonstrate the technical and economic characteristics of the sequestration activity. [1,6]

An important additional objective of the demonstration program is to create an explicit and rigorous regulatory process that gives the public and political leaders confidence in effective implementation of very large scale sequestration. A regulatory framework needs to be defined for sequestration projects, including site selection, injection operation, and eventual transfer of custody to public authorities after a period of successful operation.

Present government and private sector sequestration projects are inadequate to demonstrate the practical implementation of large scale sequestration on a timely basis.

Thus, we believe that the highest priority should be given to a program that for demonstrating $CO_2$ sequestration at megatonne scale in several geologies, following “bottom-up” site characterization. For the United States, this means about three megatonne/year projects with appropriate modeling, monitoring and verification (MMV), focusing on deep saline aquifers. Each demonstration project should last about eight to ten years. We estimate the cost for the total program to be about $500M over a decade, not including the cost of $CO_2$ acquisition. The $CO_2$ costs are likely to be considerable and highly variable depending on the acquisition strategy (natural reservoirs, capture from existing plants, supply from large scale demonstrations of new coal combustion and conversion plants). [1,6]

We estimate that for new plant construction, a $CO_2$ emission price of approximately $30/tonne (about $110/tonne C) would make CCS cost competitive with coal combustion and conversion systems without CCS. This would be sufficient to off set the cost of $CO_2$ capture and pressurization (about $25/tonne) and $CO_2$ transportation and storage (about $5/tonne). This estimate of CCS cost is uncertain; it might be larger and with new technology, perhaps smaller.

The pace of deployment of coal-fired power plants with CCS depends both on the timing and level of $CO_2$ emission prices and on the technical readiness and successful commercial demonstration of CCS technologies. The timing and the level of $CO_2$ emission prices is uncertain. However, there should be no delay in undertaking a program that would establish the option to utilize CCS at large scale in response to a carbon emission control policy that would make CCS technology economic. Sequestration rates of one to two gigatonnes of carbon (nearly four to eight gigatonnes of $CO_2$) per year by mid-century will enable appreciably enhanced coal use and significantly reduced $CO_2$ emissions.

In addition to the value of the scientific and engineering data that will emerge from this sequestration demonstration program, we should not underestimate the value of demonstrating the ability to successfully manage the program over an extended time. Such practical implementation experience will be important for public confidence in committing to very large sequestration over many decades.

Our highest priority recommendation is that as soon as possible the Congress, the Department of Energy, and other private and public sector entities work to launch a sequestration demonstration program with the characteristics identified above, including those associated with development of the regulatory system. A sense of urgency has been absent and this needs to change.

**Recommendation 2 – Avoid Picking "Technology Winners"**

Our second recommendation is for the U.S. government to provide incentives to several alternative coal combustion and conversion technologies that employ CCS. At present, Integrated Gasification Combined Cycle (IGCC) is the leading candidate for electricity production with $CO_2$ capture because it is estimated to have lower cost than pulverized coal with capture. For lower rank coals this choice may not be so clear, particularly as the traditional $CO_2$ capture technology continues to improve.

Thus, it is too early to declare IGCC the winner for all situations at this time. [1,5]. History teaches us that one single technology is almost never the winner in every situation. However, neither IGCC nor other coal technologies have been demonstrated with CCS at large scale. $CO_2$ capture will add significantly to the Cost of Electricity (COE), independent of which approach is taken.

It is critical that the government RD&D program not pick a technology "winner" especially at a time when there is great coal combustion and conversion development activity underway in the private sector in both the United States and abroad. Approaches with capture other than IGCC could prove as attractive with further technology development for example, oxygen fired pulverized coal combustion, especially with lower quality coals. Of course, there will be improvements in IGCC as well. R&D is needed on sub-systems, for example on improved $CO_2$ separation techniques for both oxygen and air driven power systems and for oxygen separation from air. The technology program would benefit from an extensive modeling and simulation effort in order to compare alternative technologies and integrated systems as well as to guide development. Novel separation schemes such as chemical looping should continue to be pursued at the process development unit (PDU) scale. The reality is that the diversity of coal type, e.g. heat, sulfur, water, and ash content, imply different operating conditions for any application and multiple technologies will likely be deployed.

The U.S. Department of Energy (DOE) program needs considerable strengthening and diversification in looking at a range of basic enabling technologies that can have major impact in the years ahead, particularly in lowering the cost of coal use in a carbon-constrained world. This work needs to be done at laboratory or process development unit scale, not as part of large integrated system demonstrations. A significant increase in the DOE coal RD&D program is called for, as well as some restructuring.

Government assistance is needed for a portfolio of coal combustion and conversion demonstration projects with $CO_2$ capture – IGCC, oxyfuel retrofits, new combustion technologies, coal to synthetic natural gas, chemicals and fuels are examples. Given the technical uncertainty and the current absence of a carbon dioxide emissions charge, there is no economic incentive for private firms to undertake such projects at any appreciable scale. The DOE coal program is not on a path to address our priority recommendations namely – enabling technology, sequestration demonstrations, coal combustion and conversion demonstrations with capture. The level of funding falls far short of what is required and perhaps as a result the program is imbalanced.

The flagship project FutureGen is consistent with our priority recommendation to initiate integrated demonstration projects at scale. However, we are concerned that the project needs more clarity in its objectives. Specifically, a project of this scale and complex system integration should be viewed as a demonstration of commercial viability at a future time when a meaningful carbon policy is in place. Its principal call on taxpayer dollars is to provide information on such commercial viability to multiple constituencies, including the investment community. To provide high fidelity information, it needs to have freedom to operate in a commercial environment.

We believe that the Congress should work with the Administration to clarify that the project objectives are commercial demonstration, not research, and reach an understanding on cost-sharing that is grounded in project realities and not in arbitrary historical formulas. In thinking about a broader set of coal technology demonstrations, including the acquisition of the $CO_2$ needed for the sequestration demonstration projects, we suggest that a new quasi-government corporation should be considered.

The 2005 Energy Policy Act contains provisions that authorize federal government assistance for coal plants containing advanced technology projects with or without CCS. We believe this assistance should be directed only to plants with CCS, both new plants and retrofit applications on existing plants.

**Recommendation 3 – Regulatory Action**

Success at capping $CO_2$ emissions ultimately depends upon adherence to $CO_2$ mitigation policies by large developed and developing economies. We see little progress to moving towards the necessary international arrangements. Although the European Union has implemented a cap-and-trade program covering approximately half of its $CO_2$ emissions, the United States has not yet adopted mandatory policies at the federal level. U.S. leadership in emissions reduction is a likely prerequisite to substantial action by emerging economies. Recent developments in the American business sector and in Congress are encouraging.

A more aggressive U.S. policy appears in line with developing public attitudes. Our study has polled the American public, following a similar poll conducted for the earlier MIT study on nuclear power. Americans now rank global warming as the number one environmental problem facing the country, and seventy percent of the American public think that the U.S. government needs to do more to reduce greenhouse gas emissions. Willingness to pay to solve this problem has grown 50% over the past three years.

**Conclusion**

In conclusion the central message of the MIT study on the *Future of Coal* is that demonstration of technical, economic, and institutional features of carbon capture and sequestration at commercial scale coal combustion and conversion plants, will (1) give policymakers and the public confidence that a practical carbon mitigation control option exists, (2) shorten the deployment time and reduce the cost for carbon capture and sequestration should a carbon emission control policy be adopted, and (3) maintain opportunities for the lowest cost and most widely available energy form to be used to meet the world's pressing energy needs in an environmentally acceptable manner.

Mr. Chairman, thank you again for inviting my testimony on this important topic.

## References


[1] *The Future of Coal – Options for a Carbon Constrained World*, Massachusetts Institute of technology, 2007. (See the web site http://web.mit.edu/coal for the report and the executive summary).

[2] Ernest J. Moniz and John M. Deutch, *Hearing on the MIT Interdisciplinary Study: The Future of Coal, Options for a Carbon-Constrained World*, Comments made to the Senate Committee on Energy and Natural Resources, 22 March 2007, Washington, D.C.

[3] *Intergovernmental Panel on Climate Change*, *Climate Change 2007: The physical science basis, Summary for Policy makers*, http://www.ipcc.ch/

[4] A few statistics from [1] that illustrate the scale of the problem

- 50% of the electricity generated in the U.S. is from coal.
- Today fossil sources account for 80% of energy demand: Coal (25%), natural gas (21%), petroleum (34%), nuclear (6.5%), hydro (2.2%), and biomass and waste (11%). Only 0.4% of global energy demand is met by geothermal, solar and wind.
- There are the equivalent of more than five hundred, 500 megawatt, coal-fired power plants in the United States with an average age of 35 years.
- China is currently constructing the equivalent of two, 500 megawatt, coal-fired power plants per week and a capacity comparable to the entire UK power grid each year.
- One 500 megawatt coal-fired power plant produces approximately 3 million tons/year of carbon dioxide ($CO_2$).
- The United States produces about 1.5 billion tons per year of $CO_2$ from coal-burning power plants.
- At present the largest sequestration project is injecting one million tons/year of carbon dioxide ($CO_2$) from the Sleipner gas field into a saline aquifer under the North Sea.

[5] James R. Katzer, *Coal-Based Power Generation with $CO_2$ Capture and Sequestration***,** Comments made to the Senate Committee**,** On Commerce, Science, and Transportation**,** Science, Energy, and Innovation Subcommittee, March 20, 2007, Washington, D.C.

[6] Julio Friedmann, *Technical Feasibility of Rapid Deployment of Geological Carbon Sequestration*, Comments made to the House Energy and Commerce Committee, Energy and Air Quality Sub-Committee. 2007: Washington, DC.