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COAL GASIFICATION TECHNOLOGIES AND THE NEED FOR LARGE SCALE PROJECTS

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BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND INNOVATION

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED TENTH CONGRESS

SECOND SESSION

APRIL 9, 2008

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COAL GASIFICATION TECHNOLOGIES AND THE NEED FOR LARGE SCALE PROJECTS

WEDNESDAY, APRIL 9, 2008

U.S. SENATE,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND INNOVATION,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 2:39 p.m. in room SR–253, Russell Senate Office Building, Hon. John F. Kerry, Chairman of the Subcommittee, presiding.

OPENING STATEMENT OF HON. JOHN F. KERRY, U.S. SENATOR FROM MASSACHUSETTS

Senator KERRY. The hearing will come to order. Thank you very much. I apologize to all for being delayed. Even though not very much is going on here, too much is going on here, if you get my drift. So I apologize for not being able to open this on time.

Thank you very, very much for joining us today to discuss the Federal Government's role in the deployment and development of carbon capture technology at coal-fired power plants. I've repeated this many times, but I think at each hearing it's important to state clearly the urgent challenge that faces our country and, indeed, the planet, with respect to the issue of global climate change.

We all know that last year the Nobel Prize-winning Intergovernmental Panel on Climate Change found that nations of the world have to reduce their greenhouse gas emissions somewhere in the range of 50 to 80 percent by mid-century in order to avert dangerous impacts of climate change.

I don't know how many of you have seen what, I think National Geographic produced, and probably Dow Chemical underwrote, the "Six Degrees" film, which was on television recently, which was a very stark and, I thought, authoritative analysis of the various computer models, the science, and what that science tells us, what with each degree of warming we may or may not face. I can assure you if you haven't seen it, it's worth the time because it really depicts, in no uncertain terms, what options are staring us in the face, in the absence of adequate response to climate change.

What is interesting is, that every time you sit down with scientists, I try to make a point of doing a fairly regular update and briefing, and that these are not the alarmist type. I think scientists by definition are conservative people. Because to be a qualified, capable scientist, you have to have a pedagogy and a protocol, and follow it pretty strictly, and subject your analyses to peer review.

And what is interesting, as Al Gore pointed out in his *An Inconvenient Truth,* the reality is that the evidence is coming back much faster in a compounding way. Scientific studies now on the table indicate that our task may be even more challenging then they all laid out only a year ago, with findings for which they won the Nobel Prize. The point I wanted to make about Al Gore is that I think there were 650 or 900, I can't recall the exact figure, peer-reviewed studies, all affirming our contribution to the problem and all affirming the man-made input.

It's really important to understand that for all of the doubters, and for all of the people who throw out sun spots and other kinds of theories, each of those has been disposed of within the scientific community. There is no peer-reviewed study whatsoever that tells us that a factor other than human beings' activities are creating climate change, or what is creating it. That's a twofold test. If you're going to doubt, you've got to show what's doing this, because everybody acknowledges it's warming. And nobody can.

What's alarming to me is that about 3 or 4 weeks ago, we received evidence that the world may need to eliminate carbon emissions altogether, within a matter of decades. Zero emissions. This science shows that coal combustion is the largest, or one of the largest contributors to global climate change.

So, we need to find a way, obviously, coal isn't going to go away, we all understand that. We know the reserves, we know the numbers on China, India, ourselves, South Korea, et cetera, so coal is not going away. It's cheap and it's abundant, and here in America we have enormous reserves, which people want to be able to use.

In China, we know, on average they're building about one pulverized coal-fired power plant per week. And that coal accounts for 80 percent of their CO_2 emissions. No matter what happens, with respect to all the efforts to reduce, China is going to equal the United States and surpass it in emissions within the next 10 years.

So, China, I say this clearly to China and to others listening, China cannot consider itself a simple, old, out of annex one, developing country any more. It's going to have to come into the fold and help to be a leader, together with India and other near-developed countries. Near-developed is at a level now that is compelling, with respect to the responsibility we all have to assume.

My staff was just over at the meetings in Bangkok and I was in Bali, and under the terminology where we have to find common but differentiated responsibilities. It's a critical issue the threading of this needle will depend on what life we give to the definition of differentiated, as well as common. The common we'll be able to identify, the differentiated we're going to have to struggle with a little bit.

That's why it's critical. This hearing is important and it's critical that we develop carbon capture and storage technology. As recommended last year in a seminal report by the Massachusetts Institute of Technology, that can enable us to capture emissions from power plants and other industrial facilities, and permanently bury them in deep saline aquifers and other geological formations. Two recent reports identified carbon capture and storage as the most promising area for emissions reductions in the electric power sector.

A December 2000 McKinsey study determined that by 2030, 9 percent of electricity could come from coal plants equipped with CCS. The Electric Power Research Institute, which is testifying before the Committee today, estimated the number at 15 percent. These studies demonstrate the tremendous potential for the application of CCS. Our government ought to be making a significant commitment to advancing this technology.

Nevertheless, in late January, the Department of Energy announced that it was cancelling FutureGen, the premier program for developing coal-fired power plants with CCS technology. The announcement brought an end to a program started 4 years ago and described, at that time, as "one of the boldest steps our Nation has taken toward a pollution-free energy future."

So today's hearing will give us the opportunity to explore the reasons for the cancellation of the program, the implications of that decision, and how, if there are not serious implications, we're going to make up for that, whatever they are, by accelerating the development and deployment of CCS technology in this country.

Many of us in the Congress are working very hard to promote this. The energy bill that passed last summer was a start. It included key provisions to inventory the country's sequestration capacity and conduct a Central Demonstration Project. Separately, I've introduced legislation with Senator Stevens, the Ranking Member of this Committee, called the Carbon Capture and Storage Technology Act of 2007, which would establish three to five commercial-scale sequestration facilities and three to five coal-fired demonstration plants with carbon capture.

We've kept hearing from the industrial sector of our country, indeed from the private sector that the big gap is the lack of any commercial-scale enterprise. So we don't know exactly what this is going to take, what the feasibility is, or what the cost is going to be in the end.

It's on this that we really want to focus today. We want to look to the testimony of this expert panel of witnesses and focus on the role of commercial-scale CCS projects, and the best way for us to advance the development and deployment of this essential technology. And, I very much look forward to exploring that with you, and I thank you all for taking the time to come here.

Senator Ensign?

STATEMENT OF HON. JOHN ENSIGN, U.S. SENATOR FROM NEVADA

Senator ENSIGN. Thank you, Mr. Chairman. I think these hearings are very important hearings. We all know that the reserves of coal that we have in the United States will continue to be a big part of our energy supply. People have talked about nuclear, and we know that we don't have a lot of nuclear expertise in this country today. Further, even if we wanted to build nuclear power plants, building them would take time, and we just don't have the capacity to build very many of them.

The electricity needs of this country are growing faster than can be met. I am a strong supporter of alternative technologies. I would ask consent, by the way, that my full statement be made part of the record.

[The prepared statement of Senator Ensign follows:]

PREPARED STATEMENT OF HON. JOHN ENSIGN, U.S. SENATOR FROM NEVADA

Mr. Chairman, I would like to thank you for holding this hearing today on "Coal Gasification Technologies and the Need for Large Scale Projects."

It is widely recognized that continued reliance on Middle East oil is neither smart energy policy nor smart security policy. In order to meet the rapidly growing energy needs of this country, we must develop the resources that are available domestically. This cannot be done using only one fuel or one technology. It must be done by using all of the resources at our disposal, including coal. As an effort to break the partisan gridlock, I introduced a broadly bipartisan bill with Senator Cantwell last week to encourage the continued development of renewable energy.

Coal is both abundant and inexpensive. In the United States alone, coal-fired power plants satisfy more than half of the Nation's energy needs, and this percentage is likely to increase in the future.

The key is to ensure that we are employing this resource in the most efficient and environmentally responsible manner possible. New technologies to make this possible are on the horizon. Carbon capture, sequestration, and IGCC technology are just a few of many processes already in development. Groundbreaking research is being conducted to develop ways to burn coal in order to maximize energy yield and employ cleaner and more efficient processes.

As most of us are aware, the FutureGen project was designed to demonstrate the feasibility of these new technologies by constructing a state-of-the-art, zero-emissions power plant. In January of this year, the Department of Energy announced that it was restructuring the FutureGen program. It's being restructured from a single demonstration project of integrated technologies to a new strategy of multiple commercial demonstration projects. While many consider this a setback, I believe that the idea of FutureGen can still be realized.

Nevada is a prime example of a state dedicated to doing its part to meet our growing energy needs and has been a national leader in generating clean energy. Nevada is committed to keeping its energy supply diverse and is planning to advance state-of-the-art, environmentally compliant, clean-coal technologies at the Ely Energy Center.

The Ely Energy Center is a 2,500 Megawatt complex that will incorporate the best available emission reduction technology today, yet provide flexibility for CO_2 removal in the future. The first two coal units will use ultra super-critical pulverized coal technology. This process uses a boiler design that produces high temperatures and pressures to improve the energy conversion efficiency. This increased efficiency results in the use of less coal per kilowatt-hour produced, which means lower emissions. In addition to the ultra super-critical boilers, the Ely Energy Center is using a water-efficient hybrid cooling method, reducing water use by 50 percent. Finally, the plant will be constructed to be carbon capture ready by setting aside sufficient real estate within the plant layout to accommodate capture equipment, once it becomes technically feasible and commercially available.

The remainder of the Ely Energy Center will be IGCC. The process of Integrated-Gas-Combined-Cycle creates a gas out of the coal that may have properties that will make the CO_2 capture easier.

In Nevada, we believe that technological advancements in carbon capture and sequestration technologies are essential to our energy future. Sierra Pacific Resources, EPRI, and several other utilities are co-sponsoring an innovative project that demonstrates a new technology to separate and capture carbon dioxide emissions from a coal-fueled power plant in Wisconsin. This technology is being tested to see whether it can be scaled up to work on larger facilities. We hope the Ely Energy Center will become home to the 3rd generation of CCS demonstration projects as EPRI continues to test such technologies.

While I believe it is vital to explore several energy sources in order to meet our growing energy needs, I also recognize that there will be times when the wind is not blowing and the sun is not shining. Coal will continue to provide the energy necessary to keep America going. We must develop the technology that allows us to utilize this abundant natural resource in a manner that is cleaner and friendlier to our environment.

I look forward to hearing from the witnesses.

Senator KERRY. Without objection, it will be.

Senator ENSIGN. Currently, Senator Cantwell and I have an alternative energy bill on the floor of the Senate that will be voted on later today. I strongly believe in alternative energies and believe that they need to be a big part of our future.

The fact is, however, that you cannot build enough solar, enough geothermal, enough wind, etc. to offset our reliance on fossil fuels. Technologies may continue to develop in the future, but right now, with our current technologies, we certainly cannot come close to meeting the growth, let alone replacing the greenhouse gas-producing emission plants that we have today.

I think it's very important that we come together and discuss the concerns about our Nation's energy security, on pumping a lot of money into countries that don't necessarily like us, and combine those with economic concerns, and environmental concerns.

In my state, to describe it simply, we have more renewable energy sources per capita than any other location in the country. The sun shines more than it does in any other state. We have several areas where we'll be able to take advantage of the wind. In eastern and parts of northern Nevada we have some of the largest geothermal "reserves" in the United States. Northern Nevada, can be powered just with geothermal.

These technologies, however, are so expensive by themselves that they cannot justify building the transmission lines. Currently, we are trying to build a coal-fired power plant in eastern Nevada. This plant would allow our state to be able to provide alternative, renewable technology throughout the State, and justify the cost of the transmission lines.

This is just one example why a coal plant is still important. First, this will be a new coal plant. We will shut down two older coal plants that are a lot less efficient and a lot dirtier. This will bring more renewable energies that are good for the environment, onboard.

One of the reasons I think it's important for holding this hearing is, to discuss the FutureGen plant closure. There are different types of coal in different parts of the country, and there are different geological environments that we need to study. I am not sure that this isn't the best strategy to find a few different sites to study the technology for not only capturing the carbon, but where to and how to sequester the carbon in an environmentally safe way. Further, I believe that we should study this, so that we can make this as commercially viable in the future as possible.

I have talked to Secretary Bodman about the Ely Energy Center, which will be the coal-fired plant that I mentioned. It's a 1,500-megawatt plant that could compete for one of these sites that the Department of Energy is talking about. Ely is a suitable site to test carbon capture and sequestration technologies.

I think that there is a bright future if we continue to invest. This really is an investment in the future of America, the future of America's energy needs, the future of America's economy, and the future of America's environment. All of these together must be examined. I think this is a very, very important hearing, and I hope that we can continue to discuss this topic in the future.

Senator KERRY. Thank you very much, Senator Ensign. And I'm delighted to have you as a Ranking Member and as a partner in this effort. I think, it's obviously bipartisan and we need just to find the most common sense approaches. I'm delighted to work with you on it, as well as on many other things. I appreciate it.

Dr. Marburger, thank you for coming up here again, you're getting to be a regular, but we enjoy that, and we're glad to have your expertise here today.

Let me just run through everybody. We've got Dr. Marburger, the Director of Office of Science and Technology Policy, Executive Office of the President; Mr. James Childress, the Executive Director of Gasification Technologies Council; Dr. Joseph Strakey, Chief Technology Officer, U.S. Department of Energy, National Energy Technology Laboratory; Michael Mudd, the Chief Executive Officer of FutureGen Alliance; David Hawkins, Director of the Climate Center, Natural Resources Defense Council, and John Novak, Executive Director of Federal and Industry Activities for Environment and Generation, of the Electric Power Research Institute. Thank you all for being here.

Dr. Marburger, would you lead off and we'll just run right down the line. We look forward to a good discussion.

Let me just remind everybody, I know you've all testified and you're old pros at this, but all of your testimony will be placed in the record in full. If you can sort of, draw it into some kind of a summary in 5 minutes, that would be great. Thanks.

STATEMENT OF HON. JOHN H. MARBURGER III, PH.D., DIRECTOR, OFFICE OF SCIENCE AND TECHNOLOGY POLICY, EXECUTIVE OFFICE OF THE PRESIDENT

Dr. MARBURGER. Thank you, Chairman Kerry, and Ranking Member Ensign. I am pleased to be here to respond to your invitation to talk about the Administration's technology initiatives to mitigate climate change. There's a lot in my written testimony and I refer you to that for filling this out. You asked me to give an overview and I'll just give a very brief summary in these oral remarks.

It's true that anthropogenic contributions to climate change are caused mostly by burning fossil fuels to produce energy, and coal is the cheapest, most abundant fossil fuel. Coal is a primary fuel for electrical power in China, which is annually adding power-generating capacity equal to that of the entire country of France.

Coal and natural gas together account for about 70 percent of the world's electric power production, and their emissions account for a similarly large percentage of greenhouse gas emissions. And most of the remainder comes from the use of petroleum, mainly for transportation.

So, strategies for substantially reducing the human production of greenhouse gases ultimately become strategies for producing energy in a way that does not release CO_2 into the atmosphere, and this is a problem of technology.

As my written testimony makes clear, this is a very difficult problem because energy is the foundation of national economies, and there is a strong incentive to use the least expensive means for producing it. Some existing energy technologies produce zero net carbon emissions, but of these, only nuclear power can be scaled up to the magnitudes necessary to meet the vast energy needs of large economies. Wind and solar are intermittent sources that will require conventional stand-by power until new energy storage technologies become available. Other sources, such as tidal or geothermal, can address only a fraction of the need.

The progress of nuclear power is inhibited by thorny issues of nuclear proliferation and spent-fuel management. Biomass is an attractive energy source because it simply recycles carbon already in the atmosphere, rather than adding to it, but it, too, is difficult to scale up to the necessary magnitude, even with enhanced technologies for extracting energy from more of its substance.

This overview suggests many opportunities for new or improved technologies, and a vigorous policy for addressing greenhouse gas emissions should address all of them. In no case, however, are existing technologies available at the necessary low price or scale—or large scale—to permit large-scale transitions to lower zero-carbon energy production in the near future.

The alternatives to new zero-carbon sources of energy production are to use less energy in the first place, and to remove carbon produced by existing fossil fuel energy technologies. Energy conservation is important in any case and should be pursued, but it can only be part of the solution. In the transportation sector, low-carbon fuels can have a great impact. For stationary power plants, capturing the carbon during the production cycle and storing it underground seems to be feasible, but efficient large-scale carbon capture technology has not been proven and the stability of underground storage arrangements has not yet been confirmed.

So this overview suggests a long list of technology opportunities that need to be pursued across the spectrum, from basic research to the development of new energy systems. And this Administration has launched initiatives for every item on the list.

My written testimony gives more detail, but the titles of these initiatives are familiar to many. Freedom Car, for example, is a hydrogen fuel initiative. Advanced Energy Initiative, FutureGen, the 20-in-10 Plan, the Coal Research Initiative, and so on. This country has a proud record of investing in technologies that can help us with these problems.

These initiatives are funded largely through the Department of Energy, and the Department of Energy is the lead agency for the President's Climate Change Technology Program announced in 2001, and including a dozen participating agencies. Their strategic plan, which is located on the program's website, which is included in my written testimony, contains much more detail.

In view of the continuing importance of coal for the world's energy supply, clean coal initiatives are particularly important, not only for the U.S., but also for many other large economies around the world, including the large Asian countries. The President has request three-quarters of a billion dollars for fossil fuel energy research development and demonstration in Fiscal Year 2009, focused almost exclusively on coal.

Funding for the Coal Research Initiative, the CRI, has grown by 87 percent over the past 3 years, and the research, development, and demonstration activities within this initiative are now almost entirely focused on carbon capture and storage technologies. The funding request for these technologies is more than triple the 2001 amount.

The Coal Research Initiative, which includes the FutureGen Program and Clean Coal Power Initiative, seeks to reduce the cost and demonstrate the commercial feasibility of coal gasification and CCS technologies. The CRI funds a full range of R&D activity, including applied research, advanced technology development, pilot-scale testing, public and stakeholder outreach, and large-demonstrations in partnership with industry. Funding requested for this program is $588 million in the 2009 budget, up 20 percent—27 percent year to year—with the FutureGen program more than doubling to $156 million.

Specific activities under the CRI, include carbon sequestration research and demonstrations, as well as R&D on advanced turbines, advanced gasifiers, and other IGCC technologies, such as those for gas cleaning, conditioning and separation.

This Administration is strongly committed to enabling cost-effective coal-based power generation, with near-zero atmospheric emissions. Coal gasification, and the associated carbon capture and sequestration technologies are an essential part of our global vision for a low-carbon future.

Mr. Chairman, you have many experts on this panel, and I will defer technical questions to them, but we're proud of the capabilities that have been brought to bear on this problem.

Thank you.

[The prepared statement of Dr. Marburger follows:]

PREPARED STATEMENT OF HON. JOHN H. MARBURGER III, PH.D., DIRECTOR, OFFICE OF SCIENCE AND TECHNOLOGY POLICY, EXECUTIVE OFFICE OF THE PRESIDENT

Chairman Kerry, Ranking Member Ensign, and Members of the Subcommittee, I am pleased to appear before you today to discuss "Coal Gasification Technologies and the Need for Large Scale Projects." My remarks will focus on some contextual factors that make coal gasification technologies particularly relevant to our climate strategy.

Fossil fuel energy production is the primary factor in the dramatic increase of atmospheric CO_2 since the beginning of the industrial revolution. A basic understanding of the science of climate change would suggest that in the short run, we should seek to produce fewer greenhouse gases and increase absorption of those already in the atmosphere. In the long run, we should aim to limit releases to an amount much smaller than current values. And we should get on this path immediately, because Earth's heat balance is already tilted and some effects of massive CO_2 production are already evident. As you know, since 2001, the Administration has taken many actions to confront this challenge, and we are continuing to make progress both domestically and internationally.

As we contemplate these actions, however, here are some numbers to keep in mind. The U.S. consumes more than 20 million barrels of oil per day, 60 billion cubic feet of natural gas per day, and 3 million tons of coal per day. This is about a fifth of the world's energy consumption. World-wide, coal accounts for about 45 percent of electricity production, natural gas about 24 percent, nuclear about 12 percent. Oil is used mainly for transportation and as a feedstock for the chemical industry. The current annual release from the world's energy sector, by far the largest contributor to increased atmospheric CO_2, is about 28 billion tons of CO_2—40 percent from coal, 40 percent from oil, and most of the remaining 20 percent from natural gas.[1]

Suppose you wanted to reduce global emissions by just one billion tons—less than 4 percent of the current global total. That would require building 136 new 1,000-MW nuclear plants (equivalent to one-third the existing world-wide nuclear capacity), or 150,000 2-MW wind turbines (about 3 times the current world capacity), or 300 new coal gasification plants (500-MW each) with carbon capture and sequestra-

[1] Energy Information Administration, *International Energy Outlook 2007, www.eia.doe.gov/oiaf/ieo/emissions.html*.

tion (CCS), in place of conventional coal plants. Today, there are several carbon sequestration projects that each remove about 1 million tons of CO_2 per year. This sounds like a lot, but is just one-thousandth of the billion we are looking for to achieve our 4 percent reduction. And international forums are talking about reductions on the order of 30 to 50 billion tons CO_2 per year by 2050.[2]

These numbers are sobering. Fossil fuels have made modern economies and the incredible advances in standard of living over the last century possible. The economic development path has been paved with fossil fuels. For any given economy, CO_2 production has been roughly proportional to Gross Domestic Product (GDP). The coefficient of proportionality is sensitive to technology; recently developed or developing economies are significantly more "carbon intensive" than older, developed economies. This is good news. It means that introducing modern energy technologies in the rapidly developing parts of the world can slow the growth of fossil CO_2 relative to the historical development path. In fact, the objective of a CO_2 mitigation strategy should be to eventually reduce the carbon intensity of the world's economy toward zero, at the lowest possible socio-economic cost.

A dramatic reduction in global energy emissions intensity will require deployment of advanced technology at a rate much higher than projected in baseline scenarios. The Energy Information Administration (EIA) projects that under current policies U.S. CO_2 emissions from energy use will increase from 5.9 billion metric tons in 2006 to 6.9 billion metric tons in 2030, an increase of 16 percent,[3] primarily as a result of increased emissions from coal power plants and vehicle emissions. Total electricity consumption is expected to grow 30 percent over that time period—an average growth rate of 1.1 percent annually (which is much slower than the historical average, largely as a result of expected efficiency gains).[4] In that timeframe, the EIA projects that about 100 gigawatts of new U.S. coal-fired generating capacity will be built (in addition to maintaining the existing capacity of 300 GW), including 30 gigawatts of integrated gasification combined-cycle (IGCC) plants without CCS.[5] From 2006 to 2030, new coal power plants are expected to increase power sector CO_2 emissions by 700 million metric tons per year, representing about three-quarters of the net increase in U.S. emissions over that time period.

Globally, the rate of emissions growth is expected to be much more rapid. In 2005, global energy-related CO_2 emissions amounted to 28 billion metric tons, of which the United States' emissions represented 21 percent.[6] By 2030, global emissions are projected to total 43 billion metric tons.[7] The EIA projects that the United States will account for about 16 percent of total global CO_2 emissions in 2030, and about 7 percent of the growth in emissions from 2005 to 2030.[8] By comparison, about 60 percent of the increase from 2005 levels is expected to come from China, India, and other non-OECD (Organization for Economic Cooperation and Development) Asian nations. U.S. coal-fired generation is projected to be 6 percent of global emissions in 2030,[9] while globally, emissions from coal combustion in all forms will grow by two-thirds, amounting to 18 billion tons-CO_2 per year (43 percent of total CO_2 emissions) by 2030.[6]

The global trends of rapid emissions growth in developing nations and a dramatic expansion of coal-related emissions have been obvious for some time. As early as 2001, it was clear that a major factor in climate policy had to be a realistic strategy for recruiting large developing economies into an international framework. It was equally clear that climate policy is strongly linked to energy policy, and that the

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[2] Japan has proposed a global 2050 goal to reduce greenhouse gas emissions to 50 percent of current levels (*i.e.,* reducing energy-related CO_2 emissions to 14 billion tons-CO_2 per year), while the EU has called for a 2050 goal of 50 percent of 1990 levels (*i.e.,* reducing energy-related CO_2 emissions to 10 billion tons-CO_2 per year). Others have proposed even more aggressive goals. Many baseline, medium- to high-growth scenarios project global emissions in the range of 50 to 70 billion tons-CO_2 per year by 2050 (*e.g.,* see the IPCC Special Report on Emissions Scenarios, *http://www.grida.no/climate/ipcc/emission/005.htm*).

[3] AEO2008 Revised Early Release (available at *http://www.eia.doe.gov/oiaf/aeo/excel/aeotab__18.xls*), which includes the expected emissions reductions resulting from the Energy Independence and Security Act of 2007.

[4] In the EIA reference case, U.S. electricity consumption, including both purchases from electric power producers and on-site generation, grows from 3,814 billion kilowatt hours in 2006 to 4,974 billion kilowatt hours in 2030, increasing at an average annual rate of 1.1 percent. In comparison, electricity consumption grew by annual rates of 7.3 percent, 4.2 percent, 2.6 percent, and 2.3 percent in the 1960s, 1970s, 1980s, and 1990s, respectively. [AEO2008 Revised Early Release]

[5] *http://www.eia.doe.gov/oiaf/aeo/excel/aeotab__9.xls.*

[6] *http://www.eia.doe.gov/pub/international/iealf/tableh1co2.xls*.

[7] *http://www.eia.doe.gov/oiaf/ieo/emissions.html*.

[8] *http://www.eia.doe.gov/oiaf/aeo/excel/aeotab__18.xls*.

[9] *http://www.eia.doe.gov/oiaf/aeo/excel/aeotab__18.xls*.

scale of the problem would require a campaign that would have to be maintained over the better part of a century. And it was clear that the already polarized nature of the public discourse was obscuring the scale and nature, not so much of the reality of anthropogenic climate change, but of the societal response that would be required.

In 2002, the President set a target of cutting our greenhouse gas intensity by 18 percent through the year 2012. When announced, this commitment was estimated to result in about 100 million metric tons of reduced carbon-equivalent emissions in 2012, with more than 500 million metric tons of reduced carbon-equivalent emissions in cumulative savings over the decade. Today, we are well ahead of the interim milestones to achieve that target. According to Environmental Protection Agency data reported to the United Nations Framework Convention on Climate Change (UNFCCC), U.S. greenhouse gas intensity declined by 2 percent in 2003, 2.5 percent in 2004, 2.2 percent in 2005, and 4.2 percent in 2006—a 10.4 percent drop in those 4 years alone.

Why shouldn't the goal be simply to reduce the absolute carbon emissions toward zero? Why bring in the notion of "intensity"? Because the cause of our climate anxiety in the first place—the root cause—is the overwhelming desire of people everywhere to improve their lot. That desire will not be denied. From all I have ever read or seen of human behavior, the will to better human circumstances must be accommodated in any social plan of action, and especially one designed to persist over decades, perhaps centuries. If we are to make any progress in mitigating anthropogenic climate change, it will be necessary to break the link between economic development and fossil fuel emissions. Economic development—*i.e.* growth in GDP—and simultaneous CO_2 reduction implies reducing carbon intensity. This is a point of the utmost importance in crafting a successful global climate strategy.

The link between GDP and fossil fuel CO_2 emissions is technology. Technology choices in a society, especially pervasive ones like energy technology, are dictated by cost. So what are the prospects for reducing the cost of low-carbon-emission technologies to the point where they will replace high-emission technologies in rapidly developing economies? I phrase the question this way to emphasize that dictating limits on carbon emissions to such a country is a fruitless exercise unless alternative, low-emission technologies are commercially available and feasible at scale. And let us be clear that if we are serious about combating anthropogenic climate change, fossil-related carbon emissions must be reduced in *all* major economies. It is not enough for only the "old rich" economies of Europe and America and Japan to eliminate their emissions. *All* major economies must eventually adopt low- or zero-carbon energy technologies. This poses a vexing economic conundrum, because adjustments in energy technologies must occur during precisely that epoch in post-Cold War history—our epoch—when a major transformation in global patterns of trade, wealth, and economic power is also occurring. Any country that intervenes in its own economy to increase the price of low-cost, high-carbon-emitting energy in order to make higher-cost, lower-emitting technology more competitive, would likely put itself at a competitive disadvantage with countries that do not have similar policies, at least in the short term. And it is likely that there will always be dissimilar policies as long as significant differences in standards of living exist among economies around the world.

The cost associated with altering the energy technology of a large economy is very large. Economists come to widely different conclusions about the cost, and frankly I do not know how to evaluate the different claims. What I do know is that today—as we speak—very few low-carbon technologies exist that can be expanded to the necessary scale in the near term. I can think of only one, nuclear fission, that is sufficiently mature and sufficiently scalable to be a serious contender with low-cost coal plants. In the short term, renewable energy technologies such as wind and solar may help slow emissions, but we do not have low-cost versions of the ancillary technologies of electrical storage and transmission that are needed to scale these up even to their current potential. Biomass looks promising for transportation fuel, but is not yet very effective in reducing CO_2 emissions overall, and is not obviously scalable to the larger electrical power industry. Nuclear power is carbon-free, but the subject of such public concern, justified or not, that its substantial expansion will come only with concerted effort.

Coal, natural gas, and petroleum will continue to be the primary energy feedstocks for decades to come. We have, however, very few full-scale demonstrations of the technologies for capturing the carbon emissions of fossil-fuel combustion. Coal is the fuel we have to worry about most, especially on the global scale. It is currently the cheapest, most ubiquitous source of energy for stationary power generation, and it releases the greatest amount of CO_2 when burned. The U.S. has vast coal reserves and about half of its electricity is generated from this fuel. Meanwhile, China already uses 2.5 times as much coal as does the United States, and is adding, on average, more than one large coal-fired power plant every 2 weeks. Other developing nations such as India and the transitional Eastern European nations are also expected to rely heavily on coal for their economic growth. Thus it is clear that development of low-cost, commercially feasible CCS technologies for coal plants is an essential component of any long-term strategy to address climate change.

The Administration has committed enormous resources for the advancement of low-carbon coal technologies. The President's 2009 budget, when combined with the private match, will result in over $1 billion of investment for research, development and demonstration of these technologies. This is just the most recent addition to the already existing $1.6 billion in tax credits and at least $8 billion in loan guarantees for advanced coal projects, industrial gasification activities at retrofitted and new facilities that incorporate carbon capture and sequestration, and advanced coal gasification facilities.

The Department of Energy (DOE) recently restructured the FutureGen program in order to focus government resources on carbon capture and storage. The new FutureGen will include multiple facilities, as opposed to just one, generating power at a commercial scale. This revamped initiative is expected to double the amount of CO_2 sequestered compared to original FutureGen concept that was announced in 2003.

The Administration has implemented a broad array of strategies—including partnerships, consumer information campaigns, incentives, and regulations—that are directed at developing and deploying cleaner, more efficient energy technologies, conservation, biological sequestration, geological sequestration and adaptation. The President's 2009 budget includes $8.6 billion for climate-change-related activities and tax incentives—an increase of 9 percent from the enacted Fiscal Year 2008 (FY08) level. Since 2001, we have spent almost $45 billion on climate science, technology development, tax incentives and international assistance. Funding for the U.S. Climate Change Technology Program (CCTP), a multi-agency R&D portfolio led by DOE, is $4.4 billion in the FY09 budget (3 percent higher than FY08 and 27 percent higher than in FY07). This represents a large increase since the CCTP program office was formally established at DOE: the CCTP portfolio in FY03 was about $2.5 billion. Also, the President's Advanced Energy Initiative (which includes the Coal Research Initiative, nuclear energy R&D, basic energy research, and energy efficiency and renewable energy R&D programs, all of which are within the CCTP portfolio) has increased 80 percent over 3 years, with $3.2 billion in the FY09 request (*versus* $1.8 billion in FY06).

The Administration is implementing mandatory regulations that will reduce carbon emissions. After calling for a renewable fuel standard and a large increase in vehicle efficiency standards in his 2007 State of the Union Address, President Bush signed into law in December the Energy Independence and Security Act of 2007, which includes substantial, mid-term requirements for vehicle fuel efficiency (40 percent improvement), renewable fuels (36 billion gallons annually by 2022), and efficiency of appliances, lighting systems, and government operations. The EIA estimates that this law will result in some of the largest emission cuts in our Nation's history, between 3.9 and 4.9 cumulative billion tons of CO_2 emissions reductions through 2030.

Internationally, President Bush has launched a Major Economies Process (MEP) to reach agreement on key elements of a post-2012 energy security and climate change arrangement under the UNFCCC, including the identification of a long term global goal for emissions reductions. The MEP will also focus on key sectors to help accelerate the development of advanced energy technologies. Japan currently outspends every other country on energy R&D—more than $3.5 billion in 2006. The U.S. was second in that year with more than $3 billion. No other country comes close. All the EU25 nations together contribute about $2.7 billion.[10] Most of Japan's energy research is on nuclear power, while most of the U.S. budget is for non-nuclear energy technology. There is much to do. Other countries can and should do more.

The Administration is pursuing global cooperation in many forums. The United States is working with other countries on a new international clean technology fund to help accelerate the use of cleaner, lower-carbon technologies and infrastructure. The United States and EU have jointly proposed in the Doha negotiations in the World Trade Organization to rapidly eliminate the tariff and non-tariff trade barriers that impede investment in clean technologies and services. The Administration has played a leadership role in the recent, legally-binding agreement with key developing countries to accelerate the phase-out of hydrochlorofluorocarbons under the

[10] International Energy Agency R&D Statistics, *http://www.iea.org/Textbase/stats/rd.asp*.

Montreal Protocol, which will reduce emissions of greenhouse gases by at least 3 billion metric tons over the coming decades. Other significant efforts include the Asia-Pacific Partnership on Clean Development and Climate with China, India, Australia, South Korea, Canada, and Japan; joint efforts to combat deforestation, which accounts for roughly 20 percent of global greenhouse gas emissions; and international collaboration on monitoring and adaptation tools, such as the Global Earth Observation System of Systems, a 72-nation collaboration that can help communities plan and prepare for the effects of climate variability and change.

In the domestic arena, many of the actions by this Administration with respect to climate change have been taken in the name of energy security. The two goals are not quite the same, the points of divergence being the increased domestic production of oil and the use of coal without carbon sequestration. That is why it is so important to invest in CCS technologies. For both climate change and energy security, technology development must focus on scalable sources—nuclear and coal, while maintaining progress in other areas such as renewable power and efficient end uses. Of course, there is no reason to delay picking the low-hanging fruit of low-carbon technology. We can increase the efficiency of cars, and convert them first to run on biofuels and later on electricity or hydrogen. We can capture the energy of wind when it blows and sun when it shines, and later when we have better batteries we can use such transient sources more effectively. We can reduce the energy consumption of lighting, of buildings, of domestic machinery and appliances, and of industrial processes, with existing technology. None of these measures, however, addresses the very large share of emissions from stationary power sources that burn fossil fuels, and particularly coal.

The above discussion suggests that reducing carbon emissions from coal power plants ought to be a high priority for federally funded R&D. Recognizing these realities, the President's request for Fossil Energy research, development and demonstration in FY09 is $754 million, which is focused almost exclusively on coal. Funding for the Coal Research Initiative (CRI) has grown by 87 percent over the past 3 years, and the research, development, and demonstration activities within this Initiative are now almost entirely focused on CCS technologies. The $588 million for CRI in FY09 compares with $170 million when the President first took office in 2001, or more than 3 times as much spending. As a result of these efforts, in partnership with industry and with other nations, coal gasification technology could enable low-cost capture and storage of a significant portion of the projected global carbon emissions over the next fifty years. But there are some big hurdles to overcome. While the United States and other coal-producing nations appear to have an abundance of potential geologic storage capacity, the stunningly large fossil fuel consumption numbers I quoted earlier highlight the immense challenges inherent in building the CCS infrastructure. Any industrial scale process has potential environmental impacts, and there are few greater industrial scales than that of power generation. The sequestration industry would have to be of comparable scale. Another challenge is cost. DOE estimates that IGCC power plants with CCS, if successfully implemented using today's technology, would generate electricity at a cost 40 to 70 percent higher than conventional coal plants. Most of that incremental cost derives from the energy penalty in capturing CO_2 from the gasified coal. Clearly, such excessive costs will inhibit the deployment of these technologies, especially on a global scale. Furthermore, the reliability of commercial-scale IGCC plants with CCS has not been suitably demonstrated.

The Coal Research Initiative (CRI), which includes the FutureGen program and Clean Coal Power Initiative (CCPI), seeks to reduce the cost and demonstrate the commercial feasibility of coal gasification and CCS technologies. The CRI funds a full range of R&D activity, including applied research, advanced technology development, pilot-scale testing, public and stakeholder outreach, and large-scale demonstrations in partnership with industry. Funding for the CRI is $588 million in the FY09 budget (an increase of 27 percent, or $124 million, above FY08), with $156 million for the FutureGen program (*versus* $74 million in FY08). Specific activities under the CRI include carbon sequestration research and demonstrations as well as R&D on advanced turbines, advanced gasifiers, and other IGCC technologies, such as those for gas cleaning, conditioning, and separation. Meanwhile, the recent refocusing of FutureGen will enhance its usefulness as a demonstration (actually, several demonstrations) of the commercial feasibility of these technologies.

In summary, the Administration remains strongly committed to a goal of enabling cost-effective, coal-based power generation with near-zero atmospheric emissions. Coal gasification—and the associated carbon capture and sequestration technologies—are an essential part of our global vision for a low-carbon future.

Thank you for the opportunity to speak with you today. I am prepared to answer any questions you have.

Senator KERRY. Thank you very much, Doctor. We'll look forward to following up on that a bit.

Mr. Childress?

STATEMENT OF JAMES M. CHILDRESS, EXECUTIVE DIRECTOR, GASIFICATION TECHNOLOGIES COUNCIL

Mr. CHILDRESS. Thank you, Mr. Chairman.

The Gasification Technologies Council is composed of more than 70 companies involved as plant owners, operators, technology suppliers, and equipment suppliers, and collectively account for about 95 percent of world gasification capacity.

I'd like to briefly summarize my written remarks, first addressing, what is gasification? It is a proven manufacturing process that converts carbon-containing materials into a synthesis gas, or a syngas, which is used to produce chemicals, plastics, fertilizer, fuels, and the subject of today's hearing—electricity.

It is not combustion—that's an important differentiation when it comes to environmental performance, both in terms of air emissions and in terms of carbon capture and storage and, if necessary, we can get into that discussion later, it is in my written testimony.

Gasification has been in commercial use for more than 50 years in the chemical and refining industry, and for more than 35 years in the power industry. Today there are more than 140 plants in operation around the world, with capacity expected to grow by another 70 percent by 2015, 80 percent of that growth will be in China. In the U.S., there are 19 operating gasification plants.

Integrated Gasification Combined Cycle (IGCC) joins a modern gasification system with an efficient combined-cycle power plant, similar to that used for natural gas combined cycle generation, that provides the most efficient, cleanest way to produce electricity from coal.

In my written statement, there is a chart that compares the air emissions of criteria pollutants for a coal-combustion plant, IGCC, natural gas and combined cycle plant. The differences are dramatic. IGCC is clearly cleaner, and it also has the potential to be the least-cost option for capturing and compressing CO_2 in new coal-based power plants using currently available equipment and processes. That's an important differentiation to note, because in combustion technologies, they're very low on the learning curve on post-combustion CO_2 removal.

More than 90 percent of gasification capacity in the world already captures CO_2. That is, chemical plants, fertilizer plants, those producing liquid and gaseous fuels, referred to as industrial gasification, already capture the CO_2, but because there's no economic or regulatory incentive, do not compress it for underground storage. They offer a lower-cost option for CO_2 capture than do power plants.

Because the manufacturing processes require the CO_2 to be removed as part of the process, carbon capture in industrial gasification is part on the sticker price, if you will. It's not an expensive option to add on, and a number of these plants are offering—in the United States—the option for near-term, large-scale carbon capture and storage at a lower cost than for power generation.

I just make reference to the Great Plains Substitute Natural Gas Plant in North Dakota where this is being done today. It's not a power plant, it's a chemical and natural gas plant. But it is capturing and selling the CO_2 for enhanced oil recovery in Canada.

Let me address the real reason for all of this, that's coal, it's what I call the "coal moratorium." IGCC projects have not been immune to the political and regulatory roadblocks facing new coal combustion plants. A number of IGCC plants in development have been either indefinitely postponed, or cancelled, because of state-level regulations, policies and programs, that require all new coal-based power generation to capture and store CO_2, right out of the box.

The net effect of this moratorium will be to increase demand for natural gas. As Senator Ensign pointed out, we do have a lot of alternatives—wind, solar, et cetera—but for base load power generation, the fuel of choice is going to be natural gas, and that is going to have an impact on price.

I have a table in my written statement that indicates that certain analysts—and I think most analysts—are saying that between now and 2020, the demand for natural gas for power generation will rise by 45 percent—that is 3 quadrillion BTUs, or 3 trillion cubic feet of natural gas demand per year.

We don't have the reserves, we don't have the production capacity. That's going to raise the price. Second, we're going to go to liquefied natural gas imports, that opens the U.S. market up to competing with higher-priced markets, basically Europe, Japan and Korea—so that the end result will be higher natural gas prices in the U.S. for industry. We're already exporting jobs overseas in many of our natural gas-dependent industries, such as chemicals, fertilizers. Industries using natural gas for fuel, homeowners will also suffer.

Industrial gasification offers one opportunity for rectifying this situation but even the industrial gasification facilities with lower CCS costs may, in fact, be faced with some of the same issues that have resulted from the coal moratorium.

My recommendations are three-fold. First, we need financial support for demonstration at a commercial scale of multiple IGCCs, using different technologies, different coals, different geological situations so we can prove out, at a commercial scale, what we can do and what it's going to cost with power generation and carbon capture and storage.

We need, financial incentives for industrial gasification that recognize its unique ability for lower cost, nearer term capture and storage, and also offer some regulatory and liability protections for these first adopters.

And finally, a uniform national policy on CO_2. We need, whatever the preference is, whatever the flavor of the day is, we need a national program for CO_2 capture, regulation, and very importantly, for the regulations involving storage. It gets to basic legal and liability issues, if we're going to move forward with CCS, and power generation and gasification.

Thank you.

Senator KERRY. National standard for the reduction?

Mr. CHILDRESS. Exactly. Yes, sir.

[The prepared statement of Mr. Childress follows:]

PREPARED STATEMENT OF JAMES M. CHILDRESS, EXECUTIVE DIRECTOR, GASIFICATION TECHNOLOGIES COUNCIL

Mr. Chairman and members of the Subcommittee, my name is James Childress. I am the Executive Director of the Gasification Technologies Council (GTC). The GTC has more than seventy companies that own and operate plants, or provide the technologies, processes, services and equipment essential to their operation. Gasification plants in which our members are involved account for more than 95 percent of world capacity.

In my testimony today I would like to address issues associated with gasification's readiness to compress and capture CO_2 and public policy steps that could be taken to accelerate commercialization of sequestration of CO_2 from IGCC power plants and gasification-based manufacturing facilities. Also, with opposition to coal-based power plants threatening to put severe price and supply pressures on natural gas, gasification technologies can help the United States meet its energy needs in environmentally and economically sound ways.

The Technology

Gasification is a proven and efficient manufacturing process that converts hydrocarbons such as coal, wastes, or biomass into a clean synthesis gas (syngas), which can be used to produce chemicals, plastics, fertilizers, fuels, and electricity. Gasification *is not* a combustion process.

Gasification has been used commercially on a global scale for more than 50 years by the chemical, refining, and fertilizer industries and for more than 35 years by the electric power industry. There are more than 420 gasifiers currently in use in some 140 facilities worldwide. Nineteen plants are operating in the United States.

Growth in the Industry

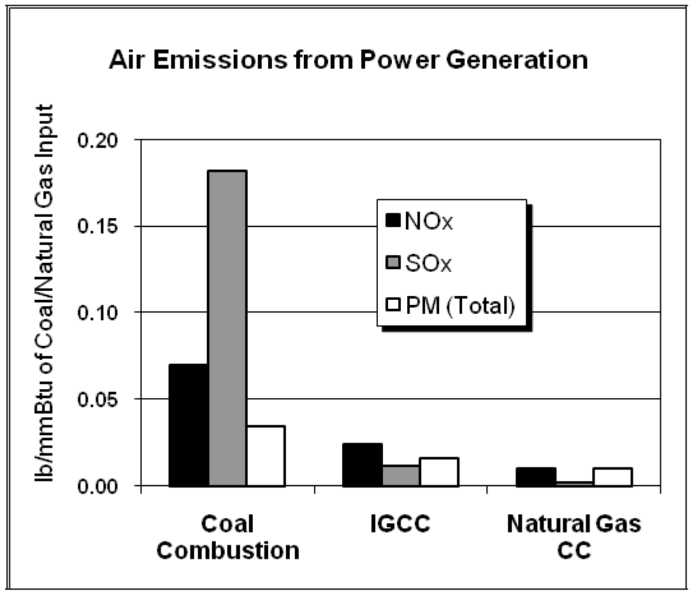
Worldwide gasification capacity is projected to grow 70 percent by 2015, with some 80 percent of the growth occurring in Asia. China is expected to achieve the most rapid growth as it moves aggressively to displace use of oil and gas in its chemicals and fertilizer industries. There are also seven coal-to-substitute natural gas projects in development in China. In addition, there are twelve proposed gasification-based IGCC power plants under evaluation by the Chinese government.

Since 2004, 29 new gasification plants have been licensed and/or built in China. In contrast, no new gasification plants have started up in the United States since 2002. In the U.S., plans have been announced for some 45–50 new gasification-based projects in twenty-five states. However, whether these plants will actually be constructed depends on a number of factors, perhaps the most important of which is the lack of a clear regulatory framework addressing carbon capture and sequestration.

Power Generation—IGCC

An Integrated Gasification Combined Cycle (IGCC) power plant combines the gasification plant with a "combined cycle" power plant. Clean syngas is combusted in high efficiency gas turbines to produce electricity. The excess heat from the gasification reaction is captured, converted into steam and sent to a steam turbine to produce additional electricity. IGCC offers both significant environmental benefits and the lowest-option for carbon capture of any coal-based power generation method.

Compared to traditional combustion-based technologies producing electricity from coal, an IGCC shows marked reductions in all criteria air pollutants, higher efficiency, and lower water use and solid waste generation. Air emissions from an IGCC approach those of a natural gas combined cycle (NGCC) plant. (Source: IL DEP, GE Energy)

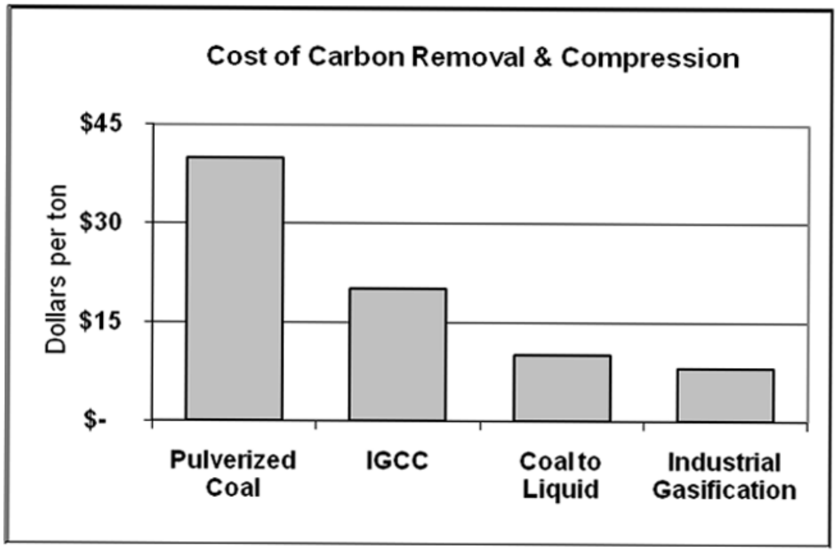


Commercial technology exists today to remove more than 95 percent of the mercury from a gasification-based plant at one-tenth the cost of removal for a coal combustion plant.

Carbon Capture

More than 80 percent of global gasification capacity is already capturing CO_2. What are commonly called "industrial gasification" facilities, chemical, plastics, fertilizer, fuels and hydrogen plants routinely capture the CO_2 as part of their manufacturing process. However, because of lack of economic incentives or regulatory requirements, the CO_2 is not sequestered.

Gasification also provides the least cost path toward capturing CO_2 emissions associated with power generation from coal, heavy petroleum residues such as petcoke and other fossil fuels. This is because the syngas being treated in an IGCC power plant is under pressure and is approximately 1 percent of the volume of post-combustion exhaust gas that must be cleansed in a conventional coal-fired plant. This results in lower capital and operating costs for the IGCC as well as reduced parasitic energy requirements. Costs of carbon capture and pressurization for industrial gasification facilities are even lower, because the equipment and processes necessary for removing CO_2 from the gas stream are part of the manufacturing process. (Source: Eastman Chemical, MIT)



Consequences of a Moratorium on Coal-based Power Generation, Including IGCC

Despite the strong environmental benefits of IGCC, coal-based IGCC plants are facing the same opposition and delay encountered by combustion-based plants. Much of this is due to demands that IGCC plants incorporate carbon capture and sequestration in their initial operations.

A prime example occurred in Florida last year when the Tampa Electric Polk Unit 6 IGCC was indefinitely postponed when the state announced greenhouse gas reductions goals, but without the necessary regulatory structure and certainty to implement those reductions. The Tampa utility has been successfully running its first IGCC at the Polk plant since the mid-1990s and expectations were that the new unit would provide valuable experience leading to increased investor and owner confidence in IGCC technology.

Since the postponement, Tampa Electric has announced that the additional capacity the new IGCC would have provided will now be met by natural gas powered generation. This scenario is typical of coal cancellations in the U.S. Despite calls for efficiency and renewables as alternatives to coal, the power generation fuel of choice is natural gas. This demand for natural gas-based power generation is accelerating because of its low emissions and higher capacity factor.

The Energy Information Administration estimates that by 2020 the use of coal for power will increase while the use of natural gas will decline. (Source: U.S. EIA)

U.S. Fuel Demand for Power Generation (Quads)

	2007	2020
Coal	20.68	23.67
Natural Gas	6.77	5.92
Renewables	3.65	5.64

The EIA forecast is clearly unrealistic—coal use will not rise under the current circumstances and gas certainly will not decline. Industry analysts have indicated that incremental natural gas demand of 3 quads will be needed to meet the expected coal shortfall, even while U.S. natural gas production has been essentially flat.

One analysis of the consequences of a de facto coal plant moratorium lays out the following scenario:

- Incremental natural gas demand will have to come from marginal gas supplies.

- North American gas fields look to be maxed out at current demand levels.
- Marginal supplies will probably need to be purchased from the global liquefied natural gas (LNG) market.
- Therefore, U.S. gas prices will be determined by much higher European and Asian prices, will be oil indexed to attract spot cargoes.

The price impacts of this rise in natural gas demand for power generation will be severe for industries such as chemicals, plastics and fertilizers that rely on natural gas as a feedstock, manufacturers that use gas as a fuel, and homeowners, already faced with skyrocketing oil and gasoline prices.

Industrial gasification offers one element of a solution—through plants gasifying coal or petroleum coke to produce chemicals, fertilizers or substitute natural gas (SNG), but the public policy and political climate is not reassuring. We propose the outline of a way forward.

Conclusions and Recommendations

There is the need for a sustained, long term carbon capture and sequestration initiative involving government and industry. The initiative should provide assurances to industry, the investment community and regulators that CCS via gasification is a viable option for capturing and sequestering CO_2 emissions from power generation and manufacturing. The elements of the initiative should include:

- Demonstration at a *commercial scale* of multiple IGCC power plants with CCS using a variety of coals;
- Incentives that recognize and reward the ability of industrial gasification to offer large scale, near term opportunities for CCS at lower costs; and
- A uniform *national* policy framework addressing regulation of CO_2 emissions and CCS, including incentives and liability indemnification for early adopters.

Thank you. I will be happy to answer any questions you may have.

APPENDIX

GASIFICATION TECHNOLOGIES COUNCIL

Gasification: Background Information

What is Gasification?

Gasification is a manufacturing process that converts carbon-containing materials, such as coal, petroleum coke ("petcoke"), biomass, or various wastes to a "synthesis gas" or "syngas" which can then be used to produce valuable products, such as, electric power, chemicals, fertilizers, substitute natural gas, hydrogen, steam, and transportation fuels.

Gasification Is Not Combustion

Gasification is a *partial* oxidation (reaction) process which produces syngas comprised primarily of hydrogen (H_2) and carbon monoxide (CO). It is *not* a *complete* oxidation (combustion) process, which produces primarily thermal energy (heat) and residual solid waste (slag), criteria air pollutants (NO_X and SO_2), and carbon dioxide (CO_2).

How Does Gasification Work?

Feedstocks

Gasification enables the capture—in an environmentally beneficial manner—of the remaining "value" present in a variety of low-grade hydrocarbon materials ("feedstocks") that would otherwise have minimal or even negative economic value.

Gasifiers can be designed to run on a single material or a blend of feedstocks:

- *Solids:* All types of coal and petroleum coke (a low value byproduct of refining) and biomass, such as wood waste, agricultural waste, and household waste.
- *Liquids:* Liquid refinery residuals (including asphalts, bitumen, and other oil sands residues) and liquid wastes from chemical plants and refineries.
- *Gas:* Natural gas or refinery/chemical off-gas.

Gasifier

The core of the gasification system is the gasifier, a pressurized vessel where the feed material contacts with oxygen (or air) and steam at high temperatures. There are several basic gasifier designs, distinguished by the use of wet or dry feed, the use of air or oxygen, the reactor's flow direction (up-flow, down-flow, or circulating), and the gas cooling process. Currently, gasifiers are capable of handling up to 3,000 tons/day of feedstock throughput and this will increase in the near future.

After being ground into very small particles—or fed directly (if a gas or liquid)—the feedstock is injected into the gasifier along with a controlled amount of air or oxygen and steam. Temperatures in a gasifier range from 1,400–2,800 degrees Fahrenheit. The heat and pressure inside the gasifier break apart the chemical bonds of the feedstock forming syngas.

The syngas consists primarily of hydrogen and carbon monoxide and, depending upon the specific gasification technology, smaller quantities of methane, carbon dioxide, hydrogen sulfide, and water vapor. Syngas can be combusted to produce electric power and steam or used as a building block for a variety of chemicals and fuels. Syngas generally has a heating value of 250–300 Btu/scf, compared to natural gas at approximately 1,000 BTU/scf.

Typically, 70 to 85 percent of the carbon in the feedstock is converted into the syngas. The ratio of carbon monoxide to hydrogen depends in part upon the hydrogen and carbon content of the feedstock and the type of gasifier used.

Oxygen Plant

Most gasification systems use almost pure oxygen (as opposed to air) to help facilitate the reaction in the gasifier. This oxygen (95 to 99 percent purity) is generated by using proven cryogenic technology. The oxygen is then fed into the gasifier through separate co-feed ports in the feed injector.

Gas Clean-Up

The raw syngas produced in the gasifier contains trace levels of impurities that must be removed prior to its ultimate use. After the gas is cooled, the trace minerals, particulates, sulfur, mercury, and unconverted carbon are removed to very low levels using commercially-proven cleaning processes common to the chemical and refining industries.

Carbon Dioxide

Carbon dioxide (CO_2) can also be removed at the gas cleanup stage using a number of commercial technologies. In fact, CO_2 is routinely removed with a commercially proven technology in ammonia and hydrogen manufacturing plants. Ammonia plants already capture roughly equivalent to 90 percent of the CO_2 and methanol plants capture approximately 70 percent.

Byproducts

Most solid and liquid feed gasifiers produce a glassy-like byproduct, which is non-hazardous and can be used in roadbed construction or in roofing materials. Also, in most gasification plants, more than 99 percent of the sulfur is removed and recovered either as elemental sulfur or sulfuric acid. Finally, for feeds (such as coal) containing mercury, more than 95 percent of the mercury can be removed from the syngas using relatively small and commercially available activated carbon beds.

Which Industries Use Gasification?

Gasification has been used in the chemical, refining, and fertilizer industries for more than 50 years and by the electric power industry for more than 35 years. Currently, there are more than 140 gasification plants—with more than 420 gasifiers—operating worldwide. Nineteen of those gasification plants are located in the United States.

The use of gasification is expanding. For example, there are several gasification projects under development to provide steam and hydrogen for synthetic crude upgrading in the oil sands industry in Canada. In addition, the paper industry is exploring how gasification can be used to make their operations more efficient and reduce waste streams.

Gasification Applications and Products

Hydrogen and carbon monoxide, the major components of syngas, are the basic building blocks of a number of other products, such as chemicals and fertilizers. In addition, a gasification plant can be designed to produce more than one product at a time (co-production or "polygeneration"), such as the production of electricity, steam, and chemicals (*e.g.,* methanol or ammonia). This polygeneration flexibility allows a facility to increase its efficiency and improve the economics of its operations.

Chemicals and Fertilizers

Modem gasification has been used in the chemical industry since the 1950s. Typically, the chemical industry uses gasification to produce methanol as well as chemicals—such as ammonia and urea—which form the foundation of nitrogen-based fertilizers. The majority of the operating gasification plants worldwide are designed to produce chemicals and fertilizers. And, as natural gas and oil prices continue to increase, the chemical industry is developing additional coal gasification plants to generate these basic chemical building blocks.

Eastman Chemical Company helped advance the use of coal gasification technology for chemicals production. Eastman's coal-to-chemicals plant in Kingsport, Tennessee, converts Appalachian coals to methanol and acetyl chemicals. The plant began operating in 1983 and has gasified approximately 10 million tons of coal with a 98 to 99 percent on-stream availability rate.

Hydrogen for Oil Refining

Hydrogen, one of the two major components of syngas, is used to strip impurities from gasoline, diesel fuel, and jet fuel, thereby producing the clean fuels required by state and Federal clean air regulations. Hydrogen is also used to upgrade heavy crude oil. Historically, refineries have utilized natural gas to produce this hydrogen. Now, with the increasing price of natural gas, refineries are looking to alternative feedstocks to produce the needed hydrogen. Refineries can gasify low value residuals, such as petroleum coke, asphalts, tars, and some oily wastes from the refining process to generate both the required hydrogen and the power and steam needed to run the refinery.

Transportation Fuels

Gasification is the foundation for converting coal and other solid fuels and natural gas into transportation fuels, such as gasoline, ultra-clean diesel fuel, jet fuel, naphtha, and synthetic oils. Two basic paths are employed in converting coal to motor fuels via gasification. In the first, the syngas undergoes an additional process, the Fischer-Tropsch (FT) reaction, to convert it to a liquid petroleum product. The FT process, with coal as a feedstock, was invented in the 1920s, used by Germany during World War II, and has been utilized in South Africa for decades. Today, it is also used in Malaysia and the Middle East with natural gas as the feedstock.

In the second process, so-called Methanol to Gasoline (MTG), the syngas is first converted to methanol (a commercially used process) and the methanol is converted to gasoline by reacting it over a bed of catalysts. A commercial MTG plant successfully operated in the 1980s and early 1990s in New Zealand and one is under development in China.

Transportation Fuels From Oil Sands

The "oil sands" in Alberta, Canada are estimated to contain as much recoverable oil (in the form of bitumen) as the vast oil fields in Saudi Arabia. However, to convert this raw material to saleable products requires mining the oil sands and refining the resulting bitumen to transportation fuels. The mining process involves massive amounts of steam to separate the bitumen from the sands and the refining process demands large quantities of hydrogen to upgrade the "crude oil" to finished products. (Wastes from the upgrading process include petcoke, deasphalted bottoms, vacuum residuals, and asphalt/asphaltenes—all of which contain unused energy.)

Traditionally, oil sand operators have utilized natural gas to produce the steam and hydrogen needed for the mining, upgrading, and refining processes. However, a number of operators will soon gasify petcoke to supply the necessary steam and hydrogen. Not only will gasification displace expensive natural gas as a feedstock, it will enable the extraction of useable energy from what is otherwise a waste product (the petcoke). In addition, black water from the mining and refining processes can be recycled to the gasifiers using a wet feed system, reducing fresh water usage and waste water management costs. (This is not inconsequential since traditional oil sand operations consume large volumes of water.)

Substitute Natural Gas

Gasification can also be used to create substitute natural gas (SNG) from coal. Using a "methanation" reaction, the coal-based syngas—chiefly carbon monoxide (CO) and hydrogen (H_2)—can be profitably converted to methane (CH_4). Nearly chemically identical to conventional natural gas, the resulting SNG can be used to generate electricity, produce chemicals/fertilizers, or heat homes and businesses. SNG will enhance domestic fuel security by displacing imported natural gas that is likely to be supplied in the form of Liquefied Natural Gas (LNG).

Power Generation With Gasification

As stated above, coal can be used as a feedstock to produce electricity from gasification. This particular coal-to-power technology allows the continued use of coal without the high level of air emissions associated with conventional coal-burning technologies. This occurs because in gasification power plants the pollutants in the syngas are removed *before* the syngas is combusted in the turbines. In contrast, conventional coal combustion technologies capture the pollutants *after* the exhaust gas has passed through the boiler or steam generator—generally using an expensive "bag house" and/or "scrubber."

IGCC Power Plants

An Integrated Gasification Combined Cycle (IGCC) power plant combines the gasification block with a "combined cycle" power block (consisting of one or more gas turbines and a steam turbine). Clean syngas is combusted in high efficiency gas turbines to produce electricity. The excess heat from the gasification reaction is then captured, converted into steam and sent to a steam turbine to produce additional electricity. The gas turbines can be operated on a backup fuel such as natural gas during periods of scheduled gasifier maintenance or can co-fire the backup fuel to compensate for any shortfall in syngas production.

Gas Turbines

In IGCC—where power generation is the focus—the clean syngas is combusted (burned) in high efficiency gas turbines to generate electricity with very low emissions. The turbines used in these plants are derivatives of proven, natural gas combined-cycle turbines that have been specially adapted for use with syngas. For IGCC plants that include carbon capture, the gas turbines must be able to operate on syngas with higher levels of hydrogen. Although modern state-of-the-art gas turbines are commercially ready for this "higher hydrogen" syngas, work is on-going in the United States to develop the next generation of even more efficient gas turbines ready for carbon capture-based IGCC.

Heat Recovery Steam Generator

Hot gas from each gas turbine in an IGCC plant will "exhaust" into a heat recovery steam generator (HRSG). The HRSG captures heat in the hot exhaust from the gas turbines and uses it to generate additional steam that is used to make more power in the steam turbine portion of the combined-cycle unit.

Steam Turbines

In most IGCC plant designs, steam recovered from the gasification process is superheated in the HRSG to increase overall efficiency output of the steam turbines, hence the name Integrated Gasification Combined Cycle. This IGCC combination, which includes a gasification plant, two types of turbine generators (gas and steam), and the HRSG is clean and efficient—producing NO_x levels less than 0.06 lb per MMBtu (coal input basis) and combined cycle efficiencies exceeding 65 percent when process stream integrated from the gasification plant is included.

Another example of the "integrated" design in the fully integrated IGCC is the IGCC gas turbine that can provide a portion of the compressed air to the oxygen plant. This reduces the capital cost of the compressors while also decreasing the amount of power required to operate the oxygen plant. Additionally, gas turbines use nitrogen from the oxygen plant to reduce combustion NO_X as well as increase power output.

Existing IGCC Power Plants

Fourteen gasification based power plants are operating around the world with one more under construction. Total capacity for these fifteen plants is 4.1 gigawatts of electricity. Numerous additional projects are planned.

In the U.S. two coal-based IGCC's have been in operation for more than a decade. The 262 MW Wabash River Coal Gasification Repowering Project (Wabash) in Indiana began commercial operation in November 1995 and helped pioneer the use of coal gasification for power in the United States. Since 1995, this facility has gasified over 1.7 million tons of bituminous coal and over 2.0 million tons of petcoke.

Tampa Electric Company also helped pioneer the use of coal gasification technology for power generation in the United States. Tampa's 250 MW Polk Power Station near Lakeland, Florida, began operating in 1996 and serves 75,000 households. The Polk plant uses high sulfur Illinois and other coals, but also blends Power River Basin coal and petcoke in order to reduce fuel costs. The Polk Power station markets the slag from the gasifier for use in manufacturing roofing and concrete blocks. Sulfuric acid, another byproduct, goes into fertilizer production.

What are the Environmental Benefits of Gasification?

Besides fuel and product flexibility, gasification-based systems offer significant environmental advantages over competing technologies, particularly coal-to-electricity combustion systems. This advantage occurs because the net volume of syngas being treated pre-combustion in an IGCC power plant is $\frac{1}{100}$ (or less) than the volume of post-combustion exhaust gas that must be cleansed in a conventional coal-fired plant.

Air Emissions

Gasification can achieve greater air emission reductions at lower cost than other technologies, such as supercritical pulverized coal. In fact, coal IGCC offers the lowest emissions of sulfur dioxide (SO_X) nitrogen oxides (NO_X) and particulate matter (PM) of any coal-based power production technology. In addition, mercury emissions can be removed from an IGCC plant at one-tenth the cost of removal for a coal combustion plant. Technology exists today to remove more than 95 percent of the mercury from a gasification based plant.

Solids Generation

During gasification, virtually all of the carbon in the feedstock is converted to syngas. The mineral material in the feedstock separates from the gaseous products, and the ash and other inert materials fall to the bottom of the gasifier as a non-leachable, glass-like solid or other marketable material. This material can be used for many construction and building applications. In addition, more than 99 percent of the sulfur can be removed using commercially proven technologies and converted into marketable elemental sulfur or sulfuric acid. (See chart).

Water Usage

Gasification uses approximately 14 to 24 percent less water to produce electric power from coal compared to other coal-based technologies and water losses during operation are about 32 to 36 percent less than other coal-based technologies. This is a major issue in many countries—such as the United States—where water supplies have already reached critical levels.

Sustainability

Gasification can help move industrial and electric power facilities toward sustainability. It can reduce the environmental footprint from low-value waste materials by utilizing them as feedstock; rather than disposing of them. By extracting the useable energy from materials that would otherwise be treated as a waste and enabling reuse of waste waters, a facility can both reduce its environmental footprint and improve its operating margins.

Carbon Dioxide

In a gasification system, CO_2 can be captured using commercially available capture technologies before it would otherwise be vented to the atmosphere. One commercially available removal technology that is used as part of carbon capture, called the water-gas shift reaction, is illustrated below:

Converting the CO to CO_2 prior to combustion is much simpler and more economical than doing so after combustion, effectively "de-carbonizing," or at least reducing the carbon in the syngas.

Plants manufacturing ammonia, hydrogen, fuels, or chemical products with a gasification system routinely capture CO_2 as part of the manufacturing process. The Dakota Gasification plant in Beulah, North Dakota, captures the CO, while making substitute natural gas. Since 2000, this plant has sent captured CO_2 via pipeline to EnCana's Weyburn oil fields in Saskatchewan, Canada, where it is used for enhanced oil recovery. To date, more than five million tons of CO_2 has been sequestered.

According to the Environmental Protection Agency the higher thermodynamic efficiency of the IGCC cycle minimizes CO_2 emissions relative to other technologies. IGCC plants offer today's least-cost alternative for capturing CO_2 from a coal-based power plant. In addition, IGCC will experience less of an energy penalty that other technologies if carbon capture is added. While CO_2 capture and sequestration will increase the cost of all forms of power generation, the U.S. Department of Energy estimates that the cost of CO_2 capture for a power plant concluded that the CO_2 capture cost is 10 percent more expensive for a conventional coal plant as for an IGCC power generation facility.

What are the Economic Benefits of Gasification?

Gasification can compete effectively in high-price energy environments. While a gasification plant is capital intensive (like any manufacturing unit), its operating costs are potentially lower than many other manufacturing processes or coal combustion plants because a gasification plant can use low-cost feedstocks, such as petcoke. Due to continued research and development efforts the cost of these units will continue to decrease.

There are a number of significant economic benefits with gasification. Inherent in the technology is its ability to convert low-value feedstocks to high-value products, thereby increasing the use of available energy in the feedstocks while reducing disposal costs. The ability to produce a number of high-value products at the same time (polygeneration) helps a facility offset its capital and operating costs. In addition, the principal gasification byproducts (sulfur and slag) are readily marketable.

Gasification offers wide fuel flexibility. A gasification plant can vary the mix of the solid feedstocks or run on natural gas or liquid feedstocks when desirable. This technology enables an industrial facility to replace its high-priced natural gas feed with lower priced feedstocks, such as coal or petcoke—thus reducing its operating costs.

For example, a refinery using gasification to manufacture hydrogen and steam can replace its natural gas feedstock with waste materials that may otherwise have to be disposed of (such as petcoke). The ability to use lower value fuels enables a refinery to reduce both its fuel and disposal costs while producing the large quantities of hydrogen that are needed for cleaner transportation fuels.

In addition, gasification units require less pollution control equipment because they generate fewer emissions; further reducing the plant's operating costs.

What is the Gasification Market Outlook?

Worldwide gasification capacity is projected to grow 70 percent by 2015, with 81 percent of the growth occurring in Asia. The prime movers behind this expected growth are the chemical, fertilizer, and coal-to-liquids industries in China, oil sands in Canada, polygeneration (hydrogen and power or chemicals) in the United States, and refining in Europe. China is expected to achieve the most rapid growth in gasification worldwide. There are seven coal-to-substitute natural gas gasification plants under development and twelve proposed IGCC plants in China. Since 2004, 29 new gasification plants have been licensed and/or built in China. In contrast, no new gasification plants have started up in the United States since 2002.

The gasification industry in the United States faces a number of challenges, including, rising construction costs and uncertainty about policy incentives and regulations. Despite these challenges, gasification is expected to grow significantly in this country.

A number of factors will contribute to a growing interest in gasification, including volatile oil and natural gas prices, more stringent environmental regulations, and a growing consensus that CO_2 management should be required in power generation and energy production. All of these factors contribute to a growing interest in gasification worldwide.

Energy Security

America is at a critical juncture in meeting its electric generating needs. Natural gas prices are volatile and while new natural gas supplies are being developed, those supplies are generally located outside the country. In addition, there is increasing concern about the need to diversify U.S. fuel requirements. Gasification is a technology that can help address some of these energy security concerns. Gasification can generate electricity and produce substitute natural gas and transportation fuels using major domestic resources such as coal or petroleum coke, thus reducing U.S. dependence on both foreign oil and foreign natural gas.

Bioprocessing

In addition to using the traditional feedstocks of coal and petroleum coke, gasifiers can utilize biomass, such as yard and crop waste, "energy crops", (such as switch grass), and waste and residual pulp/paper plant materials as feed. Municipalities as well as the paper and agricultural industries are looking for ways to reduce the disposal costs associated with these wastes and for technologies to produce electricity and other valuable products from these waste materials. While still in its infancy, biomass gasification shows a great deal of promise.

A Link to the Future

Gasification is a "link" technology to a hydrogen economy. Because gasification converts feedstocks such as coal directly into hydrogen, it can become a competitive route to producing the large quantifies of hydrogen that will be needed for fuel cells and cleaner fuels. By contrast, other technologies must first create the electricity needed to separate the hydrogen from water using electricity or expensive natural gas.

Conclusions and Recommendations

Gasification is the cleanest, most flexible way of using fossil fuels. Currently, over 80 percent of the installed worldwide gasification capacity is capturing CO_2. Gasification also provides the lowest cost option for capturing CO_2 from a fossil-fuel based power plant.

While there are strong advantages to gasification, it also faces a number of challenges, particularly for coal-to-power applications. The following are needed to help with the widespread deployment of this technology:

- Demonstration on a *commercial scale* of multiple IGCC power plants with CCS;
- Policies that recognize and reward the ability of industrial gasification" (involved in the manufacture of products and fuels) to offer large scale, near term opportunities for CCS at lower costs; and
- A uniform national policy framework addressing carbon dioxide including incentives and liability indemnification for early adopters.

Senator KERRY. Thank you very much.

Dr. Strakey?

STATEMENT OF DR. JOSEPH P. STRAKEY, JR., CHIEF TECHNOLOGY OFFICER, U.S. DEPARTMENT OF ENERGY, NATIONAL ENERGY TECHNOLOGY LABORATORY

Dr. STRAKEY. Thank you, Mr. Chairman, Senator Ensign, for inviting me to testify on DOE's coal gasification program.

My written testimony provides additional background on coal gasification, and to summarize it, it's highly flexible—gasification can use a wide variety of feedstocks, and it can also produce multiple products, including fuels. Pollutants can be reduced down to almost any desired level, and CO_2 can be easily concentrated and captured. I think we're truly approaching zero-emission coal technology.

Senator KERRY. Can you—you mind pulling the mike a little closer?

Mr. STRAKEY. Sorry.

Senator KERRY. And could you just repeat the last sentence again?

Mr. STRAKEY. I think we are truly approaching zero-emission coal technology.

We are aggressively pursuing other options, as well, namely oxy-combustion, and post-combustion capture of CO_2. We don't expect to see a single winner, but we do believe that coal gasification will play a major role in our energy future.

However, there are significant challenges that lie ahead, and that's what I'd like to talk about today.

Commercial experience with coal gasification in the United States is somewhat limited. There are only 6 gasification plants, and three of those are operating in Integrated Gasification Combined Cycle mode, to produce power.

There is virtually no experience where IGCC has been integrated with carbon capture and storage. And that's really one of the major goals of the FutureGen program. We think that without that demonstration, it's highly doubtful that any future plants would be able to be financed.

I also think that two such demonstrations would be a lot better and more convincing than one, and three would be better than two.

Reliability is always a key concern, especially when new technologies are introduced. We need additional demonstrations in the clean coal technology program, to test the technologies that are in the pipeline, and convince bankers that their investment risks are acceptable.

Our regional carbon sequestration partnerships are making great strides in advancing our knowledge of the geologic storage of carbon dioxide and about its permanence and safety. The third phase of this program is just beginning, where large volumes of CO_2 will be injected into various geologic formations, and its movement will be closely monitored and studied.

The outcome of these tests will be crucial to the public acceptance of zero-emission coal technology.

Results of the Carbon Sequestration Regional Partnership's analysis of the capacity in the United States to store carbon are very large. Deep saline formations could store all of the CO_2 emissions for North America for over 500 years, according to their upper estimate.

The storage capacity for enhanced oil recovery, however, is a lot lower. And it's also geographically limited. We need IGCC demonstrations that are coupled with storage in deep saline formations.

I would say that moving toward climate stabilization is an enormous global challenge—we need really big solutions, here. Partial solutions, such as 50 percent carbon capture, or "as good as natural gas," just won't cut it. We need to target capture levels that approach 90 percent.

The increased cost for carbon capture and storage is a very major concern. For IGCC, our studies indicate that CCS adds about 36 percent to the cost of electricity. For the combustion route, it adds over 80 percent. A large part of that huge cost increase is due to the large parasitic power that's required to run the CCS equipment—it cuts the output of the plant by over 30 percent.

I recently asked some of our systems analysis folks what I thought was a simple question—how much would it cost to implement CCS, nationwide, out to 2030? I guess I should have known that modelers don't give simple answers to simple questions.

They analyzed the scenario of a $30 a ton carbon tax, using a modification of EIA's NEMS model, to project how widely CCS technology would penetrate, both in the new and retrofit market. Their analysis showed that 40 gigawatts in new IGCC would be added, along with 100 gigawatts of retrofitted CCS capacity. In addition, it would take another 30 gigawatts of new IGCC capacity, just around the carbon capture equipment on those older plants.

The total tab attributed both to the CCS portion, alone, would be $240 billion—that's $240 billion—and that's just the capital component of the cost.

We think that R&D is the key idea on how we're going to get that enormous cost-adder down. Our program looks forward to get it to less than a 10 percent increase in the cost of electricity, and we are on a pathway to get there. My written testimony provided some specifics on the advantages we are pursuing.

Turning to FutureGen——

Senator ENSIGN. Dr. Strakey?

Mr. STRAKEY. Yes?

Senator ENSIGN. If I may, Mr. Chairman?

Did they do any cost comparisons? Because natural gas is projected to skyrocket in cost, were those comparisons done in relation to the increases projected in natural gas?

Mr. STRAKEY. Yes. The NEMS analysis allows other technologies to play against the higher cost of the $30 a ton carbon tax added on to coal, and you get a different mix of what would occur, including natural gas, nuclear, renewables, and so on.

One of the issues that you may be interested in, is that the NEMS analysis, or the model, projects a fairly low price for natural gas—I don't recall what it was offhand, but that would also, as you mentioned, impact the penetration of coal technology.

Returning to FutureGen, I've provided some background on why we need one or more commercial-scale IGCC demonstrations, integrated with carbon capture and storage in deep saline formations. I also outlined why we need to demonstrate carbon capture levels approaching 90 percent. Basically, that is FutureGen, the keystone of our program.

We're facing major challenges, and I think we have an opportunity to lead the way with coal gasification and carbon capture and sequestration.

Mr. Chairman, members of the Committee, thank you, that completes my statement.

[The prepared statement of Dr. Strakey follows:]

PREPARED STATEMENT OF DR. JOSEPH P. STRAKEY, JR., CHIEF TECHNOLOGY OFFICER, NATIONAL ENERGY TECHNOLOGY LABORATORY, U.S. DEPARTMENT OF ENERGY

Thank you Mr. Chairman and Members of the Committee. I appreciate this opportunity to provide testimony on the Department of Energy's (DOE's) Coal Gasification Research and Development (R&D) Program.

The economic prosperity of the United States over the past century has largely been built upon an abundance of fossil fuels in North America. The United States' fossil fuel resources represent a tremendous national asset. Making full use of this domestic asset in a responsible manner enables the country to fulfill its energy requirements, minimize detrimental environmental impacts, positively contribute to national security, and provide for the economic welfare of its citizens.

Coal gasification, when done in conjunction with carbon capture and storage (CCS), is one technology option that offers our Nation an attractive approach to utilize our indigenous fossil energy resources in a more efficient and environmentally sound manner for producing clean, affordable power from coal with dramatically reduced carbon emissions. Coal gasification with CCS can also reduce the carbon impact of using coal to produce ultra-clean fuels for the transportation sector, substitute natural gas (SNG) to heat our homes and fuel our industrial sector, fertilizers to ensure an abundant food supply, and chemicals that play an integral part in our every day lives.

Another coal gasification concept that could further reduce carbon dioxide (CO_2) emissions is co-feeding coal and biomass into gasifiers to produce electricity or conventional transportation fuels. The transportation fuels application is referred to as the coal-biomass-to-liquids (CBTL) process. When combined with CCS, CBTL can reduce the greenhouse gas footprint of the fuel by 20 percent (compared to petroleum) with the addition of roughly 10–18 percent by weight biomass to the coal while remaining cost competitive at today's world oil prices. Similar benefits in reduction of carbon emissions can be achieved by co-feeding coal and biomass for electricity generation in advanced gasification-based systems.

Gasification-based processes are an efficient and environmentally friendly way to produce low-cost electricity, compared with other conventional coal-conversion processes. For power generation applications, gasification technology utilizes 30–50 percent less water and produces about one-half the amount of solid wastes as conventional power plants. By the very nature of the process, sulfur oxides, nitrogen oxides, mercury, particulates, and other emissions can be reduced to near-zero levels and gasification is often the least expensive approach for the capture of CO_2.

The gasification of coal dates back as far as the end of the eighteenth century, and by the middle of the nineteenth century the basic underlying principles of gasification were fairly well understood. The use of gasification was very prominent in the latter part of the nineteenth century and the first half of the twentieth century for the production of town gas for residential and industrial use. Although this application has nearly vanished, due to its displacement by inexpensive natural gas and petroleum, new applications evolved in the industrial and manufacturing sectors.

Gasification is at the heart of many processes that offer industry low-cost, reliable, and highly-efficient options for meeting a host of market applications. Gasification-based systems are capable of utilizing all carbon-based feedstocks, either separately or in combination with one another, including coal, petroleum coke, biomass, municipal and hazardous wastes. In the gasification process, carbon-based feedstocks are converted in the gasifier in the presence of steam and oxygen at high temperatures and moderate pressure to synthesis gas, a mixture of carbon monoxide and hydrogen. The synthesis gas is cleaned of particulates, sulfur, ammonia, chlorides, mercury, and other trace contaminants to predetermined levels consistent with further downstream processing applications. At this point, various options exist for the utilization of the synthesis gas. In one option, Integrated Gasification Combined Cycle (IGCC) for the production of electricity, the cleaned synthesis gas is combusted in a high-efficiency gas turbine/generator, and the heat from the turbine exhaust gas is extracted to produce steam to drive a steam turbine/generator. Furthermore, IGCC can be readily adapted for concentrating, capturing, and sequestering CO_2.

In addition to being used for power generation, a portion or all of the synthesis gas can be chemically shifted (by reaction with steam) to a mixture of hydrogen (H_2) and CO_2. Here the H_2 and CO_2 can be separated, with the hydrogen being used in the gas turbine or highly efficient fuel cells for the production of electricity in a carbon-constrained world, while the CO_2 can be captured and sequestered. The shifted synthesis gas can also be processed in chemical reactors to produce high-quality transportation fuels, SNG, and chemicals. Gasification-based systems are the only advanced processes within the Department's research portfolio that are capable of co-producing both power as well as a wide variety of commodity and premium products to meet future market requirements.

Today, there are nineteen gasification plants operating in the United States. Nine of these plants use natural gas to produce carbon monoxide and hydrogen for synthesis of chemicals and petroleum refining, four use petroleum-based liquids for chemicals production, and six operate using solid feedstocks, *i.e.,* coal and/or petroleum coke. Of the six solid-feed gasification plants, two produce chemicals, three operate as IGCC power plants, and one produces SNG. The following are examples of gasification plants in operation in the United States today.

The largest operating coal gasification plant in the United States is the Dakota Gasification Company's Great Plains Synfuels Plant in Beulah, North Dakota. This plant was constructed with a loan guarantee from the Department of Energy and began operation in 1984. The plant has a capacity for producing up to 170 million cubic feet per day of SNG from nearly 18,500 tons per day of North Dakota lignite from an adjacent mine. The SNG is injected into an existing natural gas distribution pipeline to the Midwest. It should be noted that while the plant was a technical success, it was not a financial success: in 1985 the project sponsors defaulted on the loan, due in part to falling natural gas prices at the time, and the U.S. Treasury paid $1.550 billion to cover the guarantee.

Eastman Chemical Company operates two coal gasifiers at its Kingsport, Tennessee, chemical complex. Approximately 1,200 tons per day of eastern bituminous coal is converted to synthesis gas that is used as the building blocks for nearly 75 percent of the chemical products produced at the plant. Many of the products from this plant find their way into every day household products such as scotch tape, screwdriver handles, Kodak 35-mm film, and flat screen TV panels. In addition, products such as Tylenol® and NutraSweet® also have their origins in coal from this facility.

The Coffeyville Resources Nitrogen Fertilizer plant located in Coffeyville, Kansas, is the only other solid-feed gasification plant focusing on chemicals production, namely ammonia and urea fertilizer. This plant began operation in 2000 and today is the lowest cost manufacturer of nitrogen-based fertilizer products in North America.

Three IGCC power plants using solid feedstocks are in operation today in the United States—Tampa Electric's Polk Power Station in Tampa, Florida (250 MW_e); SG Solutions Wabash River plant in West Terre Haute, Indiana (262 MW_e); and Valero's Delaware Clean Energy Cogeneration project in Delaware City, Delaware (160 MW_e). The Florida and Indiana projects both received Federal cost-share through DOE's Clean Coal Technology Program. These two projects successfully demonstrated coal-fueled IGCC and have been instrumental in giving the utility industry confidence in IGCC technology and in generating commercial interest in IGCC deployment.

The Department's Office of Fossil Energy (FE), which manages research efforts within the Gasification Program that are implemented by the National Energy Technology Laboratory, recognizes the complex energy and environmental challenges facing America today. To address these needs, FE has a core coal R&D program that provides for the development of affordable and environmentally effective technologies to use coal. This core coal R&D program includes not only the Coal Gasification Program but also the Advanced Research (advanced materials, sensors and controls, and computational modeling), Advanced Turbines, Carbon Sequestration, Fuel Cells, Hydrogen and Fuels, and Innovations for Existing Plants Programs.

DOE is developing advanced gasification technologies to meet the most stringent environmental regulations in any state, and to facilitate the efficient capture of CO_2 for subsequent sequestration—a pathway to "near-zero atmospheric emission" coal-based energy. Gasification plants are complex systems that rely on a large number of interconnected processes and technologies. Advancements in the state-of-the-art, as well as development of novel approaches, could expand technical pathways and enable gasification to meet the demands of future markets while contributing to energy security.

Technical Issues/Hurdles—A technical report prepared by the Gasification Program in July 2002, "Gasification Markets and Technologies—Present and Future: An Industry Perspective," specifically outlines key technology issues affecting the commercial acceptance and deployment of gasification-based processes. Our coal research efforts in gasification are aimed at addressing these key issues, and good progress continues to be made toward their resolution. Foremost at that time was the need to improve process reliability and reduce capital cost. More recently, our research has expanded to address the cost and integration of gasification, particularly IGCC, with CCS.

Areas identified as significantly impacting process reliability included refractory wear, feed-injector life, and high-temperature measurement instrumentation. Areas targeted for capital cost reduction efforts included improved feeding systems capable of handling multiple feedstocks, lower cost air-separation technologies, and high-temperature gas cleaning capable of deep removal of all contaminants. Some of the significant research programs addressing these issues are described below.

Ion Transport Membranes—Conventional cryogenic air-separation technologies used in today's gasification plants are both capital and energy intensive. Typically, the cryogenic air separation constitutes 12–15 percent of the cost of an IGCC plant and can consume upwards of 10 percent of its gross power output. A promising technology being developed today that offers significant potential for cost and parasitic power reductions are known as Ion Transport Membranes (ITM). This technology has been under development by the Department, in partnership with Air Products and Chemicals, Inc. (APCI), for nearly 10 years. During this time, ITM technology has progressed from fundamental materials development to the operation of full-scale membranes and half-size modules in a 5 ton-per-day unit operating at APCI's Sparrows Point industrial gas facility near Baltimore, Maryland. Engineering analyses have consistently shown nearly a 35 percent reduction in the capital cost of the air-separation unit for an IGCC plant and nearly a one-point gain in thermal efficiency. To achieve maximum benefit, the ITM must be integrated with a gas turbine. The program is in its third phase of development that will culminate in the integrated testing of a 150 ton-per-day process module with a gas turbine that will be located at an existing coal gasificationsite in 2010. Upon successful completion of this phase, plans are being discussed for further scale-up to a 1,500 to 2,000 ton-per-day prototype unit.

High-Temperature Gas Cleanup—Removing sulfur and other impurities from coal-derived gas in an IGCC plant generally accounts for 10–12 percent of the capital investment of the plant to meet recent emissions standards. It is recognized that deep-cleaning technologies are required to meet future near-zero emission standards from coal-fired power plants, as well as achieve the desired synthesis gas purity for the production of transportation fuels and chemicals. Technologies for such deep cleaning are available, but are very costly and inefficient due to their low temperature of operation. Development of innovative deep-cleaning technologies that operate at process temperatures consistent with downstream processing applications, *i.e.,* 400 to 900 degrees Fahrenheit, would provide significant benefits. Although several approaches are being investigated, the most advanced employs a high-temperature, zinc-based sorbent in a transport reactor. Over 3,000 hours of operation with this particular sorbent have recently been completed using coal-derived synthesis gas at Eastman Chemical Company. Planning is in progress for slipstream testing of a 50-MW_e size unit at a commercial gasificationsite.

Coal-Feed Pumps—The development of coal-feed pumps will reduce the cost and improve the efficiency of all gasification-based processes. They will also improve the economics of utilization of vast low-rank coal reserves. With DOE support, Stamet Incorporated successfully developed a single-stage rotary feed pump that has the capability of injecting high-moisture coal into the high-pressure gasifier—up to 1,000 psig. In 2007, General Electric purchased Stamet for use with their gasifier technology to make their technology suitable for low-rank coal gasification. Concurrently, DOE was engaged with Pratt & Whitney Rocketdyne to also develop a coal-feed pump. Detailed design of a 400 ton-per-day pump is in progress and testing is scheduled to begin in late Fiscal Year 2009.

H_2 and CO_2 Separation Membranes—Today's technologies for CO_2 removal impose significant impacts on the thermal efficiency and capital cost of IGCC plants. It is believed that this impact can be greatly reduced through the use of advanced technologies such as membranes for separation. Furthermore, cost-effective and efficient gas separation technologies are vital in any chemical process operation and will impact the overall cost of the system. For the production of hydrogen from coal, gas separation is required for the separation of the shifted synthesis gas stream into pure H_2 and CO_2 streams. Separation of hydrogen from shifted synthesis gas is a key unit operation of any gasification-based hydrogen production system. The Gasification Program and its partner, Eltron Research and Development Company, are pursuing the development of a dense metallic-based membrane to reduce the cost and increase the performance of hydrogen separation. This membrane has achieved nearly all of DOE's 2015 performance goals for membrane-based systems. The Fuels program is also working on hydrogen separation technologies.

Coal/Biomass Gasification—The process for turning gasified coal and/or biomass into liquid transportation fuels is mature and commercially available, with technology improvements driven by the marketplace. However, the technology for co-feeding and gasifying coal-biomass mixtures is not commercially available. DOE's program includes development of technology for co-feeding and gasifying coal/biomass for electricity generation application. As with much of DOE's gasification program, DOE's FY 2009 coal/biomass research targets electricity generation applications, but could also be used by the private sector for other applications, such as production of transportation fuels. Co-feeding of coal and biomass up to about 20 percent by weight is well within the range of operability for large-scale plants. Operators of the NUON IGCC plant in Buggenum, The Netherlands, successfully fed a mixture of coal and 30 percent (by weight) demolition wood into a high-pressure, entrained-flow gasifier.

Gasification and Carbon Sequestration—DOE is taking a leadership role in the development of CCS technologies. The Carbon Sequestration Program is addressing the key challenges that confront the wide-scale deployment of capture and storage technologies through research on cost-effective capture technologies; monitoring, mitigation, and verification technologies to ensure permanent storage; permitting issues; liability issues; public outreach; and infrastructure needs. Gasification technology holds substantial promise as the best coal conversion technology option to utilize carbon capture technologies. The Gasification Program is aggressively pursuing developments to reduce the cost of carbon capture so that the cost of electricity to the public will result in an increase of less than 10 percent for new gasification-based energy plants.

FutureGen—The Department's FutureGen program offers a key opportunity to validate gasification technology coupled with CCS in commercial settings. In light of recent proposals for over 30 gasification-based commercial coal plants throughout the United States, and the potential siting issues that may require these plants to have carbon capture capability, the restructured FutureGen focuses on multiple gasification technology demonstrations with CCS in commercial plant settings. With this new strategy, the Department will help fund the CCS portion of the demonstration unit of the overall plant, thereby limiting the Department's, and taxpayer's, cost exposure. This restructured approach allows DOE to maximize the role of private sector innovation, provide a ceiling on Federal contributions, and accelerate the Administration's goal of increasing the use of clean energy technologies to help meet the steadily growing demand for energy while also mitigating greenhouse gas emissions.

In today's business environment, markets and market drivers are changing at a rapid pace. Environmental performance is a much greater factor now than in previous years as emission standards tighten. In addition, the reduction of CO_2 emissions is one of the major challenges facing industry in response to global climate change. To help meet these challenges, there is a need for more environmentally sound, flexible, efficient, and reliable systems that still meet the ever-present demand for higher profitability. Gasification is a technology that is poised to meet these requirements.

Mr. Chairman, Members of the Committee, this completes my statement. I would be happy to take any questions you may have.

Senator KERRY. Thank you, Dr. Strakey. I look forward to following up on that.

Mr. Mudd, FutureGen Alliance?

STATEMENT OF MICHAEL J. MUDD, CEO, FUTUREGEN ALLIANCE, INC.

Mr. MUDD. Thank you, Mr. Chairman.

It's an honor to be here, thank you also, Senator Ensign, Senator Stevens. My name is Michael Mudd——

Senator KERRY. Pull that there, will you? Would you just pull it toward you? There you go.

Mr. MUDD. Well, my name is Michael Mudd, I'm the Chief Executive Officer of the FutureGen Alliance, formed at the request of the U.S. Department of Energy to co-fund, design and construct the world's first near-zero emission IGCC plant with 90 percent CO_2 capture and carbon sequestration.

The Alliance is a nonprofit, global consortium comprised of 13 energy and power companies throughout the world. Prior to my current position, I had the honor of working for over 30 years at American Electric Power, where I spent a lot of time managing clean coal technology projects, including IGCC.

My remarks today will address the FutureGen partnership——

Senator KERRY. American Electric Power has a couple of plants that are IGCC now, right? Aren't they building one in Ohio?

Mr. MUDD. AEP is planning to build two IGCC plants—one in Ohio, and one in West Virginia, that is correct, Mr. Chairman.

Senator KERRY. Right.

Mr. MUDD. My remarks will address the FutureGen partnership and the impact of the DOE's proposed restructuring. The details are in my written remarks, and what I'd like to talk about today is three things which I will now summarize.

The first one is FutureGen located at Mattoon, Illinois is in the national interest, and is advancing IGCC technology with carbon capture and sequestration faster and further than any other project in the world. Climate technologies must be globally accepted and globally deployed in order for them to have maximum impact.

FutureGen at Mattoon includes international involvement at an unprecedented level, with 13 companies from 6 continents taking part. As a nonprofit enterprise, the FutureGen Alliance will be in a position to broadly share the information from the project. This will help to deploy such near-zero emission power plants throughout the world.

FutureGen at Mattoon will also meet all of the goals of the DOE program, most importantly—as Dr. Strakey said—90 percent carbon capture, which DOE has reported to Congress as critical to our energy future.

FutureGen at Mattoon also fully integrates IGCC and carbon capture and sequestration technology. The size of the components are at a full-commercial scale, therefore it will validate that performance and help to get it into the marketplace more quickly.

With respect to progress, FutureGen at Mattoon has 5 years of demonstrated success, using a first-of-a-kind siting process which can, and should, serve as a model for future plants, a site has been ready—has been picked, and is ready to go. This includes identifying all of the very complex issues associated with injecting CO_2 in these geologic formations—the legal, the liability, the regulatory and geology—all very critical, all are paving new paths that have not been done before.

A nearly 2,000-page final Environmental Impact Statement has been issued by the Department of Energy, which proves that the Mattoon site is acceptable from an environmental perspective. A team of nearly 50 engineers and scientists have completed an initial design of the plant, and a cost for the plant.

FutureGen at Mattoon has made more progress in advancing IGCC technology with carbon capture and sequestration than any other project in the world.

The second theme is about the project costs. It is important to remember that all major energy projects are being impacted by rapidly rising prices of commodity, equipment, steel, concrete, and so on. FutureGen at Mattoon's unique financing structure mitigates taxpayer exposure. The Alliance members have pledged approximately $400 million to the project, and will return all of the estimated $300 million in plan revenue back to the project, will direct all of the post-project revenue from the sale of power to benefit public R&D.

Industry financial contributors will never receive a single dollar of financial return. Such a financial arrangement is unprecedented in such a public-private partnership.

The final theme of my testimony is that the DOE's proposed restructuring falls short of addressing the national need for technology enhancement. The restructuring will result in an unacceptable termination of FutureGen at Mattoon, in favor of projects that will delay technology development by 5 years, or more.

DOE's proposed restructuring leaves many unanswered questions, which are addressed in my written testimony. It is my hope that the ongoing Congressional review surrounding IGCC, and carbon capture and sequestration, will bring an appropriate spotlight on the urgent need for large-scale projects. There remains an opportunity for the U.S. Government to reassert its position that FutureGen at Mattoon is a top priority project for advancing IGCC and CCS, with carbon capture and sequestration.

FutureGen at Mattoon should not be terminated, but instead, we need additional projects. In this way, DOE can reassume its position as a global leader in near-zero emission coal plants, and CCS development.

That concludes my opening remarks, and I welcome further questions.

Thank you.

[The prepared statement of Mr. Mudd follows:]

PREPARED STATMENT OF MICHAEL J. MUDD, CEO, FUTUREGEN ALLIANCE, INC.

The FutureGen program is a global public-private partnership formed to design, build, and operate the world's first near-zero emission coal-fueled power plant with 90 percent capture and storage of carbon dioxide (CO_2). It will determine the technical and economic feasibility of generating electricity from coal with near-zero emission technology. FutureGen has 5 years of progress behind it and is positioned to advance Integrated Gasification Combined Cycle (IGCC) and carbon capture and sequestration (CCS) technology faster and further than any other program in the world. The location of the plant will be Mattoon, Illinois. The nonprofit structure of the FutureGen Alliance, and involvement of thirteen companies that operate on six continents, is consistent with its mission to facilitate rapid deployment of near-zero emission technology not only in the United States, but throughout the world.

Climate change is one of the most pressing environmental concerns, and it is clear that Congress intends to develop policies to address this concern. Irrespective of which specific climate policy is ultimately adopted by the U.S., the success of that policy and our economic future, will hinge on the availability of affordable low-carbon technology. Nuclear, renewables, biomass, and efficiency will all be part of the low-carbon technology solution. However, given that coal is used to generate over 50 percent of the electricity in the U.S. and is projected to remain the backbone of the U.S. electricity system for most of this century, and the growing economies of China and India will be fueled with coal plants, the availability of affordable, near-zero emission coal technology, incorporating carbon capture and sequestration, is essential to our future energy security.

The Federal Government has a pivotal role to play in fostering the development, demonstration and deployment of near-zero emission coal technology. It is important that, as a Nation, we invest at the scale required to develop, prove, and deploy CCS technologies to the marketplace. While estimates vary, the required investment is certainly in excess of $10 billion over the coming decade. This investment in our Nation's future must be supported by the development and demonstration of near-zero emission coal technologies and CCS in a variety of applications.

The U.S. Department of Energy (DOE) is to be commended for its vocal support of near-zero emission coal technology, including CCS. Its support of this technology was recognized in its support of the FutureGen program as originally envisioned, but a recent proposal to restructure FutureGen fails to recognize the scale of the challenge that this Nation, and indeed the world, is facing. DOE's proposal to restructure the FutureGen program will delay technology development and integrated demonstration of commercial scale CCS by 5 years or more. It backs away from a nonprofit partnership that was created, at the request of DOE, to act in the public benefit and broadly share its technical results throughout the world. It rebuffs the participation of international companies (and countries) that are critical to the ultimate deployment of clean coal technology around the world, and it undermines the reliability of the U.S. Department of Energy—and the United States—as a dependable partner.

Therefore, regardless of what other projects or what type of structuring DOE proposes, it is essential that the Department reaffirms the Unites States' position as a global leader in near-zero emission coal technology and CCS development by maintaining the position that DOE has stated numerous times prior to its announcement of restructuring: that FutureGen at Mattoon is the top priority program in advancing CCS technologies.

FutureGen at Mattoon

FutureGen, located in Mattoon Illinois, is in the national interest and is advancing IGCC technology with CCS faster and further than any other project in the world.

- *FutureGen at Mattoon offers DOE an opportunity to beat its proposed timeline.* DOE's January 15, 2008 Request for Information (RFI) suggests an on-line date of 2015 for projects using its restructured plan. The FutureGen Alliance has already delivered 5 years of progress, including contract negotiations, an enthusiastic and committed local community, a site that is technically and legally ready to go, a design and cost estimate, a final environmental impact statement, vendor relationships, and a team of fifty engineers and scientists. No fully integrated, near-zero emission power-plant project in the world can compete with FutureGen in terms of its ability to move forward with urgency on the required technology development and demonstration.
- *FutureGen at Mattoon will meet or exceed all DOE emissions and CO_2 capture goals.* All emissions and CO_2 capture criteria included in the 2004 FutureGen Report to Congress and DOE's current Request for Information (RFI) will be met by FutureGen at Mattoon, *including 90 percent CO_2 capture.* It is imperative that DOE maintain the requirement of 90 percent CO_2 capture from the entire facility for the FutureGen program.
- *FutureGen at Mattoon is fully integrated and commercial scale.* FutureGen at Mattoon incorporates a commercial-scale gasifier and commercial-scale "Frame 7" turbine. As configured, and with the commitment to share lessons learned

widely, it gives industry a chance to learn about the cost, performance, and operating strategies for an integrated system with CCS.

- *Public benefit and information sharing is a hallmark of FutureGen at Mattoon.* As a nonprofit enterprise, the FutureGen Alliance will broadly share information from the project, facilitating the deployment of commercial, near-zero emission power plants throughout the world. It is appropriate for DOE to provide cost sharing for additional commercial CCS projects to facilitate deployment of CCS technology, but it must recognize that commercial projects by their very nature will feature protection of technological know-how and intellectual property within individual companies rather than sharing it for broad benefit.
- *International involvement is essential to the rapid deployment of CCS technologies, and FutureGen at Mattoon is a model that provides international involvement at an unprecedented level.* Thirteen companies with operations on six continents are participating as members of the Alliance. Climate technologies must be globally acceptable and globally deployed, or they will not be effective. International participation has been exceptionally well-managed and has been a cornerstone of the information sharing in the program. No other project or program can replicate FutureGen at Mattoon's level of international involvement.
- *FutureGen at Mattoon provides a platform for testing advanced technologies, which accelerates technology development and saves the taxpayer money.* Once built, and power generation, carbon capture, and sequestration operations are underway, FutureGen at Mattoon can serve as a test bed for advanced technologies emerging from DOE's Fossil Energy R&D program and industry R&D efforts. Such testing will *not* interfere with the primary mission of the facility to prove integrated CCS technology at a 90 percent capture level and sequester a minimum of one million tons per year of CO_2, and to develop and prove cost-effective approaches to advancing CCS technology. Alternative testing approaches will be far more expensive. Areas where DOE expects advancements to occur include oxygen production, gasifier improvements, gas clean-up, H_2 and CO_2 separation, H_2 turbine advancements and fuel cells. By proposing to end its support of FutureGen at Mattoon, DOE will be increasing the cost and difficulty of testing the very advanced technologies that its program managers seek to develop and deploy.

FutureGen at Mattoon's Costs

All major, global energy infrastructure projects are being impacted by rapidly rising commodity and equipment costs. FutureGen at Mattoon is no exception. Other IGCC and CCS projects also are no exception. However, FutureGen at Mattoon's unique financing structure mitigates taxpayer exposure. The Alliance has pledged approximately $400 million to the program, will return 100 percent of the estimated $300 million in plant revenues back to the program, and will direct 100 percent of post-program electricity revenues to public benefit R&D. After the program is complete, if the plant is ever sold, the Alliance has advised the DOE that it would be eligible for partial to full repayment. Industry financial contributors will never receive a single dollar of financial return. This represents an unprecedented level of commitment by the Alliance membership to a public-private partnership. The Alliance is willing to make this commitment because this investment is squarely in the interest of both the Nation and the world.

With respect to the commercial status of IGCC without CCS, while there are some IGCC plants being planned, the marketplace is still in its infancy. Only one IGCC without CCS is under construction and that plant received substantial government subsidies and required a major increase in electricity rates for it to proceed. Of the other IGCC plants in the planning stage, very few have been able to secure full financing and/or regulatory approval. The high cost of new power plants coupled with the difficulty in getting either bank financing or regulatory approval has resulted in the cancellation of many coal plants. Further, taking a broader look at coal-related plants of all technologies, according to *Source Watch,* in 2007 alone, 59 proposed plants were cancelled, abandoned, or put on hold, and of those plants remaining, few are IGCC's with real prospects of being built. The challenges in the marketplace, even when CCS is not considered, are clear. The addition of CCS with 90 percent capture fundamentally changes the underlying IGCC plant configuration—it is not a simple addition, it adds significant additional cost and complexity.

Thus, it is an appropriate role for the Federal Government to take on the challenge of building the world's first IGCC with 90 percent CCS. In the current marketplace environment, on its own, the technology simply will not come forward. With the continued funding from the U.S. DOE, FutureGen will have a high probability of proceeding.

DOE's Proposed Restructuring

The Alliance believes that it is in the national interest to *complement* FutureGen at Mattoon with additional projects in a variety of engineered applications and a variety of geologic formations. However, complementary projects must not come at the expense or delay of the number one priority, FutureGen at Mattoon. Further, it is doubtful that real projects with CCS technology that capture 90 percent of the CO_2 and sequester the CO_2 in geologic formations can be brought to fruition absent the trailblazing of FutureGen at Mattoon. Currently, DOE's proposed restructuring leaves many unanswered issues that are of concern. Some of the specific concerns about the DOE proposed restructuring include:

DOE's schedule under the restructuring proposal is unrealistic. DOE has an important obligation to the taxpayer to follow comprehensive contracting processes, conduct technology reviews, and prepare an environmental impact statement on any new project. The schedule in the RFI (*i.e.,* a proposed on-line date of 2015) is not realistic for a project that meets 100 percent of the stated goals. Many potential industrial partners are unfamiliar with DOE's required practices, and it is important that the DOE inform them of a reasonable schedule so that they can properly conduct the project and deal with their third-party investors. Overly optimistic schedules are a disservice to Congress, industry, and the public.

Based on my experience, I would envision the following as a fast-track schedule for DOE to identify an alternative, fully integrated project that meets all of the existing performance goals for the FutureGen program:

- 2009+: project selection and cooperative agreement negotiation
- 2012: completion of preliminary design, environmental impact assessment and record of decision
- 2013: completion of detailed design and procurement of major technology components
- 2017: completion of construction
- 2018: initial operation
- 2022: completion of test period

- *DOE's restructured approach has problematic business parameters.* DOE's proposal implies that 90 percent capture simply involves the addition of new technology to an existing IGCC. It does not. The complex integration of CCS into a commercial IGCC plant will entail significant modifications to many other systems, including commercial systems inside the base plant. It would also largely require a restart of design work done to date on the base commercial plant. Thus, the government, its procurement rules, and its oversight practices could easily extend into the commercial, for-profit power plant. Further, applying FutureGen funds to a project with anything appreciably less than capturing 90 percent of the *total* CO_2 emissions from the *entire* plant would fall short of what is needed to rapidly develop near-zero coal plants.
- *DOE's restructured approach does not address the increased marginal cost of electricity due to adding CCS to a plant.* The modified plant that DOE proposes that industry build *will cost substantially more to operate* than a traditional plant. DOE's RFI is largely silent on operating costs. Adding CCS to an IGCC plant is expected to increase the cost of electricity by as much as 50 percent and the marginal production cost by as much as 20 percent. Because power plants dispatch electricity to the grid based on their marginal operating cost, the approach DOE proposes could result in a plant that is too expensive for industry to operate.
- *Increased appropriations will be required to offset Federal taxation.* DOE is proposing moving away from its partnership with the nonprofit Alliance to providing Federal funds for a for-profit entity. While it is appropriate for DOE to work with for-profit and nonprofit entities, the precedent in the Clean Coal Power Initiative is that DOE grants awarded to for-profit entities can be subject to taxation by the IRS, if determined to be income. Thus, whereas 100 percent of the funding going to FutureGen at Mattoon goes to on-the-ground technology and operations, under DOE's new program, DOE will need increased appropriations if it intends to make the same ultimate on-the-ground investment in technology and operations. This could result in either: (1) hundreds of millions of

dollars of additional appropriations to offset taxes or (2) a major dilution of DOE's program investment through taxation.

- *DOE appropriately retained the 90 percent capture goal in its RFI and must do so in any awarded projects.* The FutureGen program has identified 90 percent CO_2 capture as an important requirement to advance CCS technology. This level of CO_2 capture *has significant impact on the design of many critical components of the facility, such as the combustion turbine, gas clean-up system, and syngas clean-up system.* It would be a serious mistake if this target level is relaxed. Ninety percent is a technical goal designed to ensure a sustainable future for coal in a carbon-constrained world. Today's commercial projects cannot technically or economically achieve this goal and DOE's program should focus on bold technological advances not incremental change.
- *Plant revenue must go to the industrial partner.* In a commercial project, it is expected that 100 percent of revenue would need to go to the industry partner. Unlike FutureGen at Mattoon, in which DOE shared in the project revenues substantially offsetting Federal investment, for projects conducted under DOE's new approach, a successful commercial project would insist that plant revenues go to the industrial partner so that private sector participants can generate a commercial return.

In its 2004 report "FutureGen Integrated Hydrogen and Electric Power Production and Carbon Sequestration Research Initiative", DOE acknowledged the necessity for the type and level of risk sharing associated with FutureGen at Mattoon, if technology is to advance at the required pace. In its report, DOE said:

> "FutureGen's integration of concepts and components is key to providing technical and operational viability to the generally conservative, risk-adverse coal and utility industries. Integration issues such as the dynamics between upstream and downstream subsystems (*e.g.,* between interdependent subsystems such as the coal conversion and power and hydrogen production systems and carbon separation and sequestration systems) can only be addressed by a large-scale integrated facility operation. Unless the production of hydrogen and electricity from coal integrated with sequestrating carbon dioxide can be shown to be feasible and cost competitive, the coal industry will not make the investments necessary to fully realize the potential energy security and economic benefits of this plentiful domestic energy resource."

Technology advancements and market changes in the last 5 years have not changed this need for a full scale demonstration envisioned in DOE's report and FutureGen at Mattoon.

There is no program in the world that can move near-zero emission power and CCS faster or further than FutureGen at Mattoon. The FutureGen Alliance is non-profit, includes unprecedented international involvement and information sharing, and has a site that is technically and legally ready to go. Alternatives will cost the country 5 years or more of delay and/or deliver less in terms of results.

As Congress and the administration debate the appropriate structure for the FutureGen program, the Alliance urges that all of these factors be taken into account. FutureGen at Mattoon should be maintained as a global flagship program that is the Nation's top priority for advancing near-zero emission coal technology, and complementary projects should be added to the program as the budget allows.

Senator KERRY. Thank you, Mr. Mudd.

Mr. Hawkins? Thanks for your many years of effort at this.

STATEMENT OF DAVID G. HAWKINS, DIRECTOR, CLIMATE CENTER, NATURAL RESOURCES DEFENSE COUNCIL

Mr. HAWKINS. Thank you very much, Mr. Chairman, for inviting me to present NRDC's views on carbon capture, on coal, climate protection, and the role of gasification.

Today, coal use and climate protection are on a collision course, and coal is at the center of that collision. Coal is ubiquitous, it is abundant, and if one ignores its environmental costs, it comes to the marketplace at low cost.

Because it's so abundant, it's going to be very difficult to convince political leaders to walk away from coal. It would take decades to do it, in my opinion, and we don't have decades.

So, a critical need today is to develop a method for changing the investments in the coal plants that are being built—being proposed here in the United States as you mentioned—and being built very rapidly in countries like China.

The reason that this is so critical is the magnitude of the global warming pollution that would come from those new coal plants, and how much more difficult it would make our job.

There are about 3,000 new coal plants that are on the drawing boards, globally, for construction in the next 25 years—about two-thirds of those in the developing world, and about 40 percent in China. If those plants operated for 60 years—which is a typical lifetime—and they released all of their CO_2 into the atmosphere, the total would be astounding—it would be about 750 billion tons of carbon dioxide. To put that number in perspective, that's 30 percent more emissions than all emissions from coal use in previous human history, and that's with 25 years worth of investments in coal plants alone.

So you can see that we've got a huge train coming at us that we have to address without delay. Otherwise we're going to make this problem of protecting the climate, impossible.

There is an answer for the coal plants that are built: carbon capture and geologic disposal technologies are ready for use today and gasification is a commercially demonstrated component of that system.

What we need is not an R&D program, we need a technology framework for deploying these technologies, and a policy that is supportive.

We recommend three parts of a package, in order to make this happen. First, enactment of a comprehensive cap-and-trade legislation on global warming emissions. We need this, in order to put the Nation on a path to achieve the needed reductions; we need it to provide flexibility that can keep costs low; and most importantly we need it to provide a reason for investing in carbon capture technology in the first place. Without an emissions cap program, and without a requirement for capture, there's no economic rationale to capture the carbon.

The second element of this—to get the program, to get this deployment happening faster, is what we call a low-carbon generation obligation. This would overcome a major financial problem. Right now, someone wants to built a new project—absent specific large government subsidies, all of the costs would fall on the ratepayers of that particularly company, and not surprisingly, a lot of them are hesitant to do that.

A low-carbon generation obligation would have the merit of spreading the incremental costs of these first projects over the entire electric generating system, and providing this technology to be demonstrated at very low cost to any individual ratepayer.

The third thing that we recommend is a new source performance standard for new coal generation. We simply shouldn't build new coal plants without capturing the carbon.

The first rule of holes is, when you're in one, stop digging. And building a new coal plant that emits all of its CO_2 in the atmosphere will simply make us dig our hole deeper.

But, if we combine these measures, we can stimulate the immediate deployment of this technology. I would say, today, that if something like the Lieberman-Warner climate bill were law today, that the FutureGen project would be under construction today—we wouldn't be sitting here talking about why it was encountering all of these obstacles—it would be built.

So, I would say, in concluding, that if Congress takes steps to enact these policies, and programs in this Congress, we'll be on our way to addressing this problem, we'll be on our way to avoiding the lock-in of a huge amount of new global warming emissions associated with new coal plants, and we will be able to demonstrate the commercial reliability and feasibility of these new technologies, and that is something that the world will take notice of. And it is something that will engage countries like China, and India, and help us solve this problem.

Thank you.

[The prepared statement of Mr. Hawkins follows:]

PREPARED STATEMENT OF DAVID G. HAWKINS, DIRECTOR, CLIMATE CENTER, NATURAL RESOURCES DEFENSE COUNCIL

Thank you for the opportunity to testify today on coal gasification and carbon capture technologies. My name is David Hawkins. I am Director of the Climate Center at the Natural Resources Defense Council (NRDC). NRDC is a national, nonprofit organization of scientists, lawyers and environmental specialists dedicated to protecting public health and the environment. Founded in 1970, NRDC has more than 1.2 million members and online activists nationwide, served from offices in New York, Washington, Los Angeles and San Francisco, Chicago and Beijing.

Today, the U.S. and other developed nations around the world run their economies largely with industrial sources powered by fossil fuel and those sources release billions of tons of carbon dioxide (CO_2) into the atmosphere every year. There is national and global interest today in capturing that CO_2 for disposal or sequestration to prevent its release to the atmosphere, something that can be achieved with commercially demonstrated coal gasification systems. To distinguish this industrial capture system from removal of atmospheric CO_2 by soils and vegetation, I will refer to the industrial system as carbon capture and disposal or CCD.

The interest in CCD stems from a few basic facts. We now recognize that CO_2 emissions from use of fossil fuel result in increased atmospheric concentrations of CO_2, which along with other so-called greenhouse gases, trap heat, leading to an increase in temperatures, regionally and globally. These increased temperatures alter the energy balance of the planet and thus our climate, which is simply nature's way of managing energy flows. Documented changes in climate today along with those forecast for the next decades, are predicted to inflict large and growing damage to human health, economic well-being, and natural ecosystems.

Coal is the most abundant fossil fuel and is distributed broadly across the world. It has fueled the rise of industrial economies in Europe and the U.S. in the past two centuries and is fueling the rise of Asian economies today. Because of its abundance, coal is cheap and that makes it attractive to use in large quantities if we ignore the harm it causes. However, per unit of energy delivered, coal today is a bigger global warming polluter than any other fuel: double that of natural gas; 50 percent more than oil; and, of course, enormously more polluting than renewable energy, energy efficiency, and, more controversially, nuclear power. To reduce coal's contribution to global warming, we must deploy and improve systems that will keep the carbon in coal out of the atmosphere, specifically systems that capture carbon dioxide (CO_2) from coal-fired power plants and other industrial sources for safe and effective disposal in geologic formations.

The Toll From Coal

Before turning to the status of CCD let me say a few words about coal use generally. The role of coal now and in the future is controversial due to the damages its production and use inflict today and skepticism that those damages can or will be reduced to a point where we should continue to rely on it as a mainstay of industrial economies. Coal is cheap and abundant compared to oil and natural gas. But the toll from coal as it is used today is enormous. From mining deaths and illness and devastated mountains and streams from practices like mountain top removal mining, to accidents at coal train crossings, to air emissions of acidic, toxic, and heat-trapping pollution from coal combustion, to water pollution from coal mining and combustion wastes, the conventional coal fuel cycle is among the most environmentally destructive activities on Earth. Certain coal production processes are inherently harmful and while our society has the capacity to reduce many of today's damages, to date, we have not done so adequately nor have we committed to doing so. These failures have created well-justified opposition by many people to continued or increased dependence on coal to meet our energy needs.

Our progress of reducing harms from mining, transport, and use of coal has been frustratingly slow and an enormous amount remains to be done. Today mountain tops in Appalachia are destroyed to get at the coal underneath and rocks, soil, debris, and waste products are dumped into valleys and streams, destroying them as well. Waste impoundments loom above communities (including, in one particularly egregious case, above an elementary school) and thousands of miles of streams are polluted. In other areas surface mine reclamation is incomplete, inadequately performed and poorly supervised due to regulatory gaps and poorly funded regulatory agencies.

In the area of air pollution, although we have technologies to dramatically cut conventional pollutants from coal-fired power plants, in 2004 only one-third of U.S. coal capacity was equipped with scrubbers for sulfur dioxide control and even less capacity applied selective catalytic reduction (SCR) for nitrogen oxides control. And under the Administration's so-called CAIR rule, even in 2020 nearly 30 percent of coal capacity will still not employ scrubbers and nearly 45 percent will lack SCR equipment. Moreover, because this administration has deliberately refused to require use of available highly effective control technologies for the brain poison mercury, we will suffer decades more of cumulative dumping of this toxin into the air at rates several times higher than is necessary or than faithful implementation of the Clean Air Act would achieve. Finally, there are no controls in place for CO_2, the global warming pollutant emitted by the more than 330,000 megawatts of coal-fired plants; nor are there any CO_2 control requirements adopted today for old or new plants save in California.

Mr. Chairman and members of the Committee, the environmental community has been criticized in some quarters for our generally negative view regarding coal as an energy resource. But consider the reasons for this. Our community reacts to the facts on the ground and those facts are far from what they should be if coal is to play a role as a responsible part of the 21st century energy mix. Rather than simply decrying the attitudes of those who question whether using large amounts of coal can and will be carried out in a responsible manner, the coal industry in particular should support policies to correct today's abuses and then implement those reforms. Were the industry to do this, there would be real reasons for my community and other critics of coal to consider whether their positions should be reconsidered.

The Need for CCD

Turning to CCD, NRDC supports rapid deployment of such capture and disposal systems for sources using coal. Such support is not a statement about how dependent the U.S. or the world should be on coal and for how long. Any significant additional use of coal that vents its CO_2 to the air is fundamentally in conflict with the need to keep atmospheric concentrations of CO_2 from rising to levels that will produce dangerous disruption of the climate system. Given that an immediate world-wide halt to coal use is not plausible, analysts and advocates with a broad range of views on coal's role should be able to agree that, if it is safe and effective, CCD should be rapidly deployed to minimize CO_2 emissions from the coal that we do use.

Today coal use and climate protection are on a collision course. Without rapid deployment of CCD systems, that collision will occur quickly and with spectacularly bad results. The very attribute of coal that has made it so attractive—its abundance—magnifies the problem we face and requires us to act now, not a decade from now. Until now, coal's abundance has been an economic boon. But today, coal's abundance, absent corrective action, is more bane than boon.

Since the dawn of the industrial age, human use of coal has released about 150 billion metric tons of carbon into the atmosphere—about half the total carbon emissions due to fossil fuel use in human history. But that contribution is the tip of the carbon iceberg. Another 4 *trillion* metric tons of carbon are contained in the remaining global coal resources. That is a carbon pool nearly seven times greater than the amount in our pre-industrial atmosphere. Using that coal without capturing and disposing of its carbon means a climate catastrophe.

And the die is being cast for that catastrophe today, not decades from now. Decisions being made today in corporate board rooms, government ministries, and Congressional hearing rooms are determining how the next coal-fired power plants will be designed and operated. Power plant investments are enormous in scale, more than $1 billion per plant, and plants built today will operate for 60 years or more. The International Energy Agency (IEA) forecasts that more than $5 trillion will be spent globally on new power plants in the next 25 years. Under IEA's forecasts, over 1,800 gigawatts (GW) of new coal plants will be built between now and 2030—capacity equivalent to 3,000 large coal plants, or an average of ten new coal plants every month for the next quarter century. This new capacity amounts to 1.5 times the total of all the coal plants operating in the world today.

The astounding fact is that under IEA's forecast, 7 out of every 10 coal plants that will be operating in 2030 don't exist today. That fact presents a huge opportunity—many of these coal plants will not need to be built if we invest more in efficiency; additional numbers of these coal plants can be replaced with clean, renewable alternative power sources; and for the remainder, we can build them to capture their CO_2, instead of building them the way our grandfathers built them.

If we decide to do it, the world could build and operate new coal plants so that their CO_2 is returned to the ground rather than polluting the atmosphere. But we are losing that opportunity with every month of delay—10 coal plants were built the old-fashioned way last month somewhere in the world and 10 more old-style plants will be built this month, and the next and the next. Worse still, with current policies in place, none of the 3,000 new plants projected by IEA are likely to capture their CO_2.

Each new coal plant that is built carries with it a huge stream of CO_2 emissions that will likely flow for the life of the plant—60 years or more. Suggestions that such plants might be equipped with CO_2 capture devices later in life might come true but there is little reason to count on it. As I will discuss further in a moment, while commercial technologies exist for pre-combustion capture from gasification-based power plants, most new plants are not using gasification designs and the few that are, are not incorporating capture systems. Installing capture equipment at these new plants after the fact is implausible for traditional coal plant designs and expensive for gasification processes.

If all 3,000 of the next wave of coal plants are built with no CO_2 controls, their lifetime emissions will impose an enormous pollution lien on our children and grandchildren. Over a projected 60-year life these plants would likely emit 750 billion tons of CO_2, a total, from just 25 years of investment decisions, that is 30 percent greater than the total CO_2 emissions from all previous human use of coal. Once emitted, this CO_2 pollution load remains in the atmosphere for centuries. Half of the CO_2 emitted during World War I remains in the atmosphere today.

In short, we face an onrushing train of new coal plants with impacts that must be diverted without delay. What can the U.S. do to help? The U.S. is forecasted to build nearly 300 of these coal plants, according to reports and forecasts published by the U.S. EIA. We should adopt a national policy that new coal plants be required to employ CCD without delay. By taking action ourselves, we can speed the deployment of CCD here at home and set an example of leadership. That leadership will bring us economic rewards in the new business opportunities it creates here and abroad and it will speed engagement by critical countries like China and India.

To date our efforts have been limited to funding research, development, and limited demonstrations. Such funding can help in this effort if it is wisely invested. But government subsidies—which are what we are talking about—cannot substitute for the driver that a real market for low-carbon goods and services provides. That market will be created only when requirements to limit CO_2 emissions are adopted. In this Congress serious attention is finally being directed to enactment of such measures.

Key Questions About CCD

I started studying CCD in detail 10 years ago and the questions I had then are those asked today by people new to the subject. Do reliable systems exist to capture CO_2 from power plants and other industrial sources? Where can we put CO_2 after we have captured it? Will the CO_2 stay where we put it or will it leak? How much disposal capacity is there? Are CCD systems "affordable"? To answer these questions, the Intergovernmental Panel on Climate Change (IPCC) decided 4 years ago to prepare a special report on the subject. That report was issued in September 2005 as the IPCC Special Report on Carbon Dioxide Capture and Storage. I was privileged to serve as a review editor for the report's chapter on geologic storage of CO_2.

CO_2 Capture

The IPCC special report groups capture or separation of CO_2 from industrial gases into four categories: post-combustion; pre-combustion; oxyfuel combustion; and industrial separation. I will say a few words about the basics and status of each of these approaches. In a conventional pulverized coal power plant, the coal is combusted using normal air at atmospheric pressures. This combustion process produces a large volume of exhaust gas that contains CO_2 in large amounts but in low concentrations and low pressures. Commercial post-combustion systems exist to capture CO_2 from such exhaust gases using chemical "stripping" compounds and they have been applied to very small portions of flue gases (tens of thousands of tons from plants that emit several million tons of CO_2 annually) from a few coal-fired power plants in the U.S. that sell the captured CO_2 to the food and beverage industry. However, industry analysts state that today's systems, based on publicly available information, involve much higher costs and energy penalties than the principal demonstrated alternative, pre-combustion capture.

New and potentially less expensive post-combustion concepts have been evaluated in laboratory tests and some, like ammonia-based capture systems, are scheduled for small pilot-scale tests in the next few years. Under normal industrial development scenarios, if successful such pilot tests would be followed by larger demonstration tests and then by commercial-scale tests. These and other approaches should continue to be explored. However, unless accelerated by a combination of policies, subsidies, and willingness to take increased technical risks, such a development program could take one or two decades before post-combustion systems would be accepted for broad commercial application.

Pre-combustion capture is applied to coal conversion processes that gasify coal rather than combust it in air. In the oxygen-blown gasification process coal is heated under pressure with a mixture of pure oxygen, producing an energy-rich gas stream consisting mostly of hydrogen and carbon monoxide. Coal gasification is widely used in industrial processes, such as ammonia and fertilizer production around the world. Hundreds of such industrial gasifiers are in operation today. In power generation applications as practiced today this "syngas" stream is cleaned of impurities and then burned in a combustion turbine to make electricity in a process known as Integrated Gasification Combined Cycle or IGCC. In the power generation business, IGCC is a relatively recent development—about two decades old and is still not widely deployed. There are two IGCC power-only plants operating in the U.S. today and about 14 commercial IGCC plants are operating, with most of the capacity in Europe. In early years of operation for power applications a number of IGCC projects encountered availability problems but those issues appear to be resolved today, with Tampa Electric Company reporting that its IGCC plant in Florida is the most dispatched and most economic unit in its generating system.

Commercially demonstrated systems for pre-combustion capture from the coal gasification process involve treating the syngas to form a mixture of hydrogen and CO_2 and then separating the CO_2, primarily through the use of solvents. These same techniques are used in industrial plants to separate CO_2 from natural gas and to make chemicals such as ammonia out of gasified coal. However, because CO_2 can be released to the air in unlimited amounts under today's laws, except in niche applications, even plants that separate CO_2 do not capture it; rather they release it to the atmosphere. Notable exceptions include the Dakota Gasification Company plant in Beulah, North Dakota, which captures and pipelines more than one million tons of CO_2 per year from its lignite gasification plant to an oil field in Saskatchewan, and ExxonMobil's Shute Creek natural gas processing plant in Wyoming, which strips CO_2 from sour gas and pipelines several million tons per year to oil fields in Colorado and Wyoming.

Today's pre-combustion capture approach is not applicable to the installed base of conventional pulverized coal in the U.S. and elsewhere. However, it is ready today for use with IGCC power plants. The oil giant BP has announced an IGCC project with pre-combustion CO_2 capture at a site in California. When operational the project will gasify petroleum coke, a solid fuel that resembles coal more than petroleum to make electricity for sale to the grid. The captured CO_2 will be sold to an oil field operator in California to enhance oil recovery. The principal obstacle for broad application of pre-combustion capture to new power plants is not technical, it is economic: under today's laws it is cheaper to release CO_2 to the air rather than capturing it. Enacting laws to limit CO_2 pollution can change this situation, as I discuss later.

While pre-combustion capture from IGCC plants is the approach that is ready today for commercial application, it is not the only method for CO_2 capture that may emerge if laws creating a market for CO_2 capture are adopted. I have previously mentioned post-combustion techniques now being explored. Another approach, known as oxyfuel combustion, is also in the early stages of research and development. In the oxyfuel process, coal is burned in oxygen rather than air and the exhaust gases are recycled to build up CO_2 concentrations to a point where separation at reasonable cost and energy penalties may be feasible. Small scale pilot studies for oxyfuel processes have been announced. As with post-combustion processes, absent an accelerated effort to leapfrog the normal commercialization process, it could be one or two decades before such systems might begin to be deployed broadly in commercial application.

Given the massive amount of new coal capacity scheduled for construction in the next two decades, we cannot afford to wait until we see if these alternative capture systems prove out, nor do we need to. Coal plants in the design process today can employ proven IGCC and precombustion capture systems to reduce their CO_2 emissions by about 90 percent. Adoption of policies that set a CO_2 performance standard now for such new plants will not anoint IGCC as the technological winner since alternative approaches can be employed when they are ready. If the alternatives prove superior to IGCC and pre-combustion capture, the market will reward them accordingly. As I will discuss later, adoption of CO_2 performance standards is a critical step to improve today's capture methods and to stimulate development of competing systems.

I would like to say a few words about so-called "capture-ready" or "capture-capable" coal plants. Some years ago I was under the impression that some technologies like IGCC, initially built without capture equipment could be properly called "capture-ready." However, the implications of the rapid build-out of new coal plants for global warming and many conversations with engineers since then have educated me to a different view. Unfortunately, the term "capture-ready" has been embraced by industry lobbyists in a manner that strips the concept of any meaning. According to some industry representatives, a power plant that simply leaves physical space for an unidentified black box deserves to be called "capture-ready." If that makes a power plant "capture-ready" Mr. Chairman, then my driveway is "Ferrari-ready." We should not be investing today in coal plants at more than a billion dollars apiece with nothing more than a hope that some kind of capture system will turn up. We would not get on a plane to a destination if the pilot told us there was no landing site but options were being researched.

It is correct that an IGCC unit built without capture equipment can be equipped later with such equipment and at much lower cost than attempting to retrofit a conventional pulverized coal plant with today's demonstrated post-combustion systems. However, the costs and engineering reconfigurations of such an approach are substantial. More importantly, we need to begin capturing CO_2 from new coal plants without delay in order to keep global warming from becoming a potentially runaway problem. Given the pace of new coal investments in the U.S. and globally, we simply do not have the time to build a coal plant today and think about capturing its CO_2 down the road.

Geologic Disposal

We have a significant experience base for injecting large amounts of CO_2 into geologic formations. For several decades oil field operators have received high pressure CO_2 for injection into fields to enhance oil recovery, delivered by pipelines spanning as much as several hundred miles. Today in the U.S. a total of more than 35 million tons of CO_2 are injected annually in more than 70 projects. (Unfortunately, due to the lack of any controls on CO_2 emissions, about 80 percent of that CO_2 comes from natural CO_2 formations rather than captured from industrial sources. Historians will marvel that we persisted so long in pulling CO_2 out of holes in the ground in order to move it hundreds of miles and stick in back in holes at the same time we were recognizing the harm being caused by emissions of the same molecule from nearby large industrial sources.) In addition to this enhanced oil recovery experience, there are several other large injection projects in operation or announced. The longest running of these, the Sleipner project, began in 1996.

But the largest of these projects injects on the order of one million tons per year of CO_2, while a single large coal power plant can produce about five million tons per year. And of course, our experience with man-made injection projects does not extend for the thousand year or more period that we would need to keep CO_2 in place underground for it to be effective in helping to avoid dangerous global warming. Accordingly, the public and interested members of the environmental, industry and policy communities rightly ask whether we can carry out a large scale injection program safely and assure that the injected CO_2 will stay where we put it.

Let me summarize the findings of the IPCC on the issues of safety and efficacy of CCD. In its 2005 report the IPCC concluded the following with respect to the question of whether we can safely carry out carbon injection operations on the required scale:

> "With appropriate site selection based on available subsurface information, a monitoring programme to detect problems, a regulatory system and the appropriate use of remediation methods to stop or control CO_2 releases if they arise, the local health, safety and environment risks of geological storage would be comparable to the risks of current activities such as natural gas storage, EOR and deep underground disposal of acid gas."

The knowledge exists to fulfill all of the conditions the IPCC identifies as needed to assure safety. While EPA has authority regulate large scale CO_2 injection projects its current underground injection control regulations are not designed to require the appropriate showings for permitting a facility intended for long-term retention of large amounts of CO_2. With adequate resources applied, EPA should be able to adopt the necessary revisions to its rules in one to 2 years. While EPA has announced its intention to issue a proposed rule this year, intense oversight by Congress is likely to be needed to assure this happens.

Do we have a basis today for concluding that injected CO_2 will stay in place for the long periods required to prevent its contributing to global warming? The IPCC report concluded that we do, stating:

> "Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99 percent over 100 years and is likely to exceed 99 percent over 1,000 years."

Despite this conclusion by recognized experts there is still reason to ask what are the implications of imperfect execution of large scale injection projects, especially in the early years before we have amassed more experience? Is this reason enough to delay application of CO_2 capture systems to new power plants until we gain such experience from an initial round of multi-million ton "demonstration" projects? To sketch an answer to this question, my colleague Stefan Bachu, a geologist with the Alberta Energy and Utilities Board, and I wrote a paper for the Eighth International Conference on Greenhouse Gas Control Technologies in June 2006. The obvious and fundamental point we made is that without CO_2 capture, new coal plants built during any "delay and research" period will put 100 percent of their CO_2 into the air and may do so for their operating life if they were "grandfathered" from retrofit requirements. Those releases need to be compared to hypothetical leaks from early injection sites.

Our conclusions were that even with extreme, unrealistically high hypothetical leakage rates from early injection sites (10 percent per year), a long period to leak detection (5 years) and a prolonged period to correct the leak (1 year), a policy that delayed installation of CO_2 capture at new coal plants to await further research would result in cumulative CO_2 releases twenty times greater than from the hypothetical faulty injectionsites, if power plants built during the research period were "grandfathered" from retrofit requirements. If this wave of new coal plants were all required to retrofit CO_2 capture by no later than 2030, the cumulative emissions would still be four times greater than under the no delay scenario. I believe that any objective assessment will conclude that allowing new coal plants to be built without CO_2 capture equipment on the ground that we need more large scale injection experience will always result in significantly greater CO_2 releases than starting CO_2 capture without delay for new coal plants now being designed.

The IPCC also made estimates about global storage capacity for CO_2 in geologic formations. It concluded as follows:

> "Available evidence suggests that, worldwide, it is likely that there is a technical potential of at least about 2,000 $GtCO_2$ (545 GtC) of storage capacity in geological formations. There could be a much larger potential for geological storage in saline formations, but the upper limit estimates are uncertain due to lack of information and an agreed methodology."

Current CO_2 emissions from the world's power plants are about 10 Gt (billion metric tons) per year, so the IPCC estimate indicates 200 years of capacity if power plant emissions did not increase and 100 years capacity if annual emissions doubled.

Policy Actions to Speed CCD

As I stated earlier, research and development funding is useful but it cannot substitute for the incentive that a genuine commercial market for CO_2 capture and disposal systems will provide to the private sector. The amounts of capital that the private sector can spend to optimize CCD methods will almost certainly always dwarf what Congress will provide with taxpayer dollars. To mobilize those private sector dollars, Congress needs a stimulus more compelling than the offer of modest handouts for research. Congress has a model that works: intelligently designed policies to limit emissions cause firms to spend money finding better and less expensive ways to prevent or capture emissions.

Where a technology is already competitive with other emission control techniques, for example, sulfur dioxide scrubbers, a cap and trade program like that enacted by Congress in 1990, can result in more rapid deployment, improvements in performance, and reductions in costs. Today's scrubbers are much more effective and much less costly than those built in the 1980s.

However, a CO_2 cap and trade program by itself may not result in deployment of CCD systems as rapidly as we need. Many new coal plant design decisions are being made literally today. Depending on the pace of required reductions under a global warming bill, a firm may decide to build a conventional coal plant and purchase credits from the cap and trade market rather than applying CCD systems to the plant. While this may appear to be economically rational in the short term, it is likely to lead to higher costs of CO_2 control in the mid and longer term if substantial amounts of new conventional coal construction leads to ballooning demand for CO_2 credits. Recall that in the late 1990s and the first few years of this century, individual firms thought it made economic sense to build large numbers of new gas-fired power plants. The problem is too many of them had the same idea and the resulting increase in demand for natural gas increased both the price and volatility of natural gas to the point where many of these investments are idle today.

Moreover, delaying the start of CCD until a cap and trade system price is high enough to produce these investments delays the broad demonstration of the technology that the U.S. and other countries will need if we continue substantial use of coal as seem likely. The more affordable CCD becomes, the more widespread its use will be throughout the world, including in rapidly growing economies like China and India. But the learning and cost reductions for CCD that are desirable will come only from the experience gained by building and operating the initial commercial plants. The longer we wait to ramp up this experience, the longer we will wait to see CCD deployed here and in countries like China.

Accordingly, we believe the best policy package is a hybrid program that combines the breadth and flexibility of a cap and trade program with well-designed performance measures focused on key technologies like CCD. One such performance measure is a CO_2 emissions standard that applies to new power investments. California enacted such a measure in S.B. 1368 last year. It requires new investments for sale of power in California to meet a performance standard that is achievable by coal with a moderate amount of CO_2 capture.

Another approach is a low-carbon generation obligation for coal-based power. Similar in concept to a renewable performance standard, the low-carbon generation obligation requires an initially small fraction of sales from coal-based power to meet a CO_2 performance standard that is achievable with CCD. The required fraction of sales would increase gradually over time and the obligation would be tradable. Thus, a coal-based generating firm could meet the requirement by building a plant with CCD, by purchasing power generated by another source that meets the standard, or by purchasing credits from those who build such plants. This approach has the advantage of speeding the deployment of CCD while avoiding the "first mover penalty." Instead of causing the first builder of a commercial coal plant with CCD to bear all of the incremental costs, the tradable low-carbon generation obligation would spread those costs over the entire coal-based generation system. The builder of the first unit would achieve far more hours of low-carbon generation than required and would sell the credits to other firms that needed credits to comply. These credit sales would finance the incremental costs of these early units. This approach provides the coal-based power industry with the experience with a technology that it knows is needed to reconcile coal use and climate protection and does it without sticker shock.

A bill introduced last year, S. 309, contains such a provision. It begins with a requirement that one-half of one per cent of coal-based power sales must meet the low-carbon performance standard starting in 2015 and the required percentage increases over time according to a statutory minimum schedule that can be increased in specified amounts by additional regulatory action.

A word about costs is in order. With today's off the shelf systems, estimates are that the production cost of electricity at a coal plant with CCD could be as much as 40 percent higher than at a conventional plant that emits its CO_2. But the impact on average electricity prices of introducing CCD now will be very much smaller due to several factors. First, power production costs represent about 60 percent of the price you and I pay for electricity; the rest comes from transmission and distribution costs. Second, coal-based power represents just over half of U.S. power consumption. Third, and most important, even if we start now, CCD would be applied to only a small fraction of U.S. coal capacity for some time. Thus, with the trading approach I have outlined, the incremental costs on the units equipped with CCD would be spread over the entire coal-based power sector or possibly across all fossil capacity depending on the choices made by Congress. Based on CCD costs available in 2005 we estimate that a low-carbon generation obligation large enough to cover all forecasted new U.S. coal capacity through 2020 could be implemented for about a two per cent increase in average U.S. retail electricity rates.

Recent Congressional Action

Title VII of the Energy Independence and Security Act of 2007 (EISA) contains some provisions that, if funded, will help to make CCD a reality. These include authorizations to conduct at least seven large-scale geologic sequestration projects and separate authorizations for projects for large-scale capture of CO_2 from industrial sources. A third provision requires the U.S. Geological Survey to carry out a comprehensive assessment of capacity for geologic disposal of CO_2.

NRDC supports implementation of these provisions but we urge that they be complemented with enactment this year of a comprehensive program to cap CO_2 and other greenhouse gases, along with complementary policies to accelerate CCD deployment. Enacting such a cap and trade bill will demonstrate the policy resolve to shift to lower-emitting energy investments, including CCD. That will help ensure that the demonstrations called for in EISA are integrated with commercial energy investments rather than being carried out with a science experiment mentality. It will also spur much more cost-effective cost-sharing arrangements with industry since these projects will help industry participants meet their obligations under a cap and trade program. As is shown by legislation like the Lieberman-Warner Climate Security Act, S. 2191, such comprehensive legislation can provide much larger resources to promote early CCD projects than the amounts authorized by EISA, even if the EISA funds were fully appropriated.

NRDC believes that the large-scale projects in EISA should be implemented as an integral component of a policy to move forward with near-term deployment of CCD. New coal-fired power plants continue to be proposed in the U.S. and it is essential that any such plants should employ CCD. EISA's large-scale injection projects can serve as repositories for the CO_2 produced by such plants. Thus, these projects should not be thought of as short-term operations that will be operated for a few years and then shut down. Any early "demonstration" projects should be permitted by EPA for operation as permanent repositories. Such projects also should use anthropogenic CO_2, as opposed to the use of naturally occurring or recycled CO_2 used in most enhanced oil recovery projects today.

Finally, I want to repeat the importance of prompt adoption of permitting and operational requirements for CO_2 disposal by EPA. While EPA has announced an intention to propose rules this year, we encourage this Committee to work with the Environment and Public Works and the Appropriations Committees to assure that EPA adopts final rules in an expeditious manner.

Conclusions

To sum up, since we will almost certainly continue using large amounts of coal in the U.S. and globally in the coming decades, it is imperative that we act now to deploy CCD systems. Commercially demonstrated CO_2 capture systems exist today and competing systems are being researched. Improvements in current systems and emergence of new approaches will be accelerated by requirements to limit CO_2 emissions. Commercial deployment of such systems will only happen with enactment of comprehensive climate bills that cap CO_2 and incorporate complementary policies to promote accelerated deployment of CCD. Geologic disposal of large amounts of CO_2 is viable and we know enough today to conclude that it can be done safely and effectively. EPA must act without delay to revise its regulations to provide the necessary framework for efficient permitting, monitoring and operational practices for large scale permanent CO_2 repositories.

Finally CCD is an important strategy to reduce CO_2 emissions from fossil fuel use but it is not the basis for a climate protection program by itself. Increased reliance on low-carbon energy resources is the key to protecting the climate. The lowest carbon resource of all is smarter use of energy; energy efficiency investments will be the backbone of any sensible climate protection strategy. Renewable energy will need to assume a much greater role than it does today. With today's use of solar, wind and biomass energy, we tap only a tiny fraction of the energy the sun provides every day. There is enormous potential to expand our reliance on these resources. We have no time to lose to begin cutting global warming emissions. Fortunately, we have technologies ready for use today that can get us started.

Mr. Chairman, that completes my testimony, I will be happy to take any questions you or other committee members may have.

Senator KERRY. Well, thank you, Mr. Hawkins.

I, personally, couldn't agree with you more, but we'll talk about that a lot more in a second.

Mr. Novak?

STATEMENT OF JOHN NOVAK, EXECUTIVE DIRECTOR, FEDERAL AND INDUSTRY ACTIVITIES, ENVIRONMENT AND GENERATION, ELECTRIC POWER RESEARCH INSTITUTE

Mr. NOVAK. Good afternoon, Chairman Kerry, Ranking Member Ensign, and Senator Stevens.

I'm John Novak, Executive Director of Federal and Industry activities at the Electric Power Research Institute and as I hope you know, EPRI conducts research and development on technology, operations and the environment, for the global electric power industry.

As Senator Kerry mentioned, last November my colleague, Dr. Bryan Hannegan testified before this committee, this Subcommittee, about our PRISM and MERGE analyses. These analyses show the need for, and the value of, having a full portfolio of technologies, including end- use energy efficiency, renewable nuclear power, advanced coal with CO_2 capture and storage, and plug-in hybrid electric vehicles in order to meet future electricity demand, and to meet global climate change goals.

As EPRI's President, Steve Specker, has said on numerous occasions about technologies, "We need them all."

Information on the PRISM/MERGE analysis can be found in a recent, the Fall issue of our EPRI journal, and I've provided copies for the Subcommittee. One fundamental implication of our work is very clear—we must move from analysis to action if we are to deploy this full portfolio of technologies in a timely and effective manner. For coal, this implies a full portfolio of coal technologies.

We're talking about IGCC, IGCC—particularly when you plan to capture and store CO_2—has some advantages over traditional pulverized coal. But today's IGCC designs have some disadvantages, as well.

EPRI's *Coalfleet for Tomorrow®* program has identified the RD&D pathways to demonstrate, by 2025, a full portfolio of economically attractive, commercial-scale, advanced coal-powered integrated CO_2 capture and storage technologies suitable for use within the broad range of U.S. coal types, and information on that pathway is included in my testimony.

The key to proving CO_2 capture and storage capability is a demonstration of CO_2 capture and storage at large scale—at IGCC, for pulverized coal and for oxy-combustion—the storage of the CO_2 in a variety of geologies. Large, combined capture and storage demonstrations should be encouraged in different regions, and with different coals and technologies.

To help move from analysis to action, EPRI has identified a number of demonstration projects that target critical gaps, that must be achieved to achieve this full portfolio of technologies.

Five of the critical projects are aimed at demonstrating the effectiveness, and reducing the cost, of CO_2 capture and storage from coal plants. These five coal projects include two projects for demonstrating different post-combustion CO_2 capture technologies with storage, one with American Electric Power and one with the Southern company—it includes a project to demonstrate IGCC operation with integrated CO_2 capture and storage, a high-efficiency pulverized coal plant with state-of-the-art emissions controls, and integrated CO_2 capture and storage—we call that our UltraGen project—and the demonstration of a key enabling technology to lower the cost of oxygen production for IGCC and oxy-combustion plants.

These projects are designed to compliment ongoing private and government sector activities. All of these critical demonstration projects were identified through EPRI's collaborative process, and we expect to participate in each of them. But they are electricity-sector projects, not EPRI projects. Each will require a consortium of companies, drawing on both private sector and government funding, as appropriate for each project.

EPRI and its members are further evaluating these projects and, in some cases, are already moving forward on a plan to fund and implement each project.

EPRI appreciates the opportunity to provide testimony to the Subcommittee on this important topic, and I would be happy to answer any questions.

Thank you.

[The prepared statement of Mr. Novak follows:]

PREPARED STATEMENT OF JOHN NOVAK, EXECUTIVE DIRECTOR, FEDERAL AND INDUSTRY ACTIVITIES, ENVIRONMENT AND GENERATION, ELECTRIC POWER RESEARCH INSTITUTE

Introduction

Thank you, Mr. Chairman, Ranking Member Ensign, and Members of the Subcommittee. I am John Novak, Executive Director of Federal and Industry Activities for the Environment and Generation Sectors of the Electric Power Research Institute (EPRI). EPRI conducts research and development on technology, operations and the environment for the global electric power industry. As an independent, non-profit Institute, EPRI brings together its members, scientists and engineers, along with experts from academia, industry and other centers of research to:

- collaborate in solving challenges in electricity generation, delivery and use;
- provide technological, policy and economic analyses to drive long-range research and development planning; and
- support multi-discipline research in emerging technologies and issues.

EPRI's members represent more than 90 percent of the electricity generated in the United States, and international participation extends to 40 countries. EPRI has major offices and laboratories in Palo Alto, California; Charlotte, North Carolina; Knoxville, Tennessee, and Lenox, Massachusetts.

EPRI appreciates the opportunity to provide testimony to the Subcommittee on the topic of integrated gasification combined cycle (IGCC) technologies and the need for large scale IGCC demonstration projects that feature CO_2 capture and sequestration.

Integrated Gasification Combined Cycle (IGCC)

In integrated gasification combined cycle plants, coal or petroleum coke is partially oxidized with oxygen to CO and hydrogen, the impurities cleansed in an acid gas removal process and the clean gas (called "syngas") burned in a combined cycle to produce electricity. The energy use in the cycle is integrated between the gasification section and the power block, hence the name.

There are only six IGCC plants in the world operating on coal. These operating units also use petroleum coke or blends due to its lower price. One, the Vresova IGCC based in the Czech Republic (Lurgi-type gasifier) is 350 MW. The others are each about 250 MW. The two in the United States are Wabash (Conoco Phillips gasifier) and Polk (GE gasifier) in Indiana and Florida. Two additional IGCCs in Europe are Buggenum, Netherlands and Puertollano, Spain (both variations on the Shell gasifier). A new IGCC started operation this year at Nakoso, Japan (MHI gasifier). Chemical plants around the world have accumulated a 100-year experience base operating coal-based gasification units and related gas cleanup processes. The most advanced of these units are similar to the front end of a modern IGCC facility. Similarly, several decades of experience firing natural gas and petroleum distillate have established a high level of maturity for the basic combined cycle generating technology.

IGCC technology is still relatively new and needs more commercial installations. Based on the limited data available, today's IGCC plants are available 5–7 percent fewer hours per year than conventional pulverized coal (PC) plants. While it is likely that IGCC will "catch up" with PC, the initial learning curve on all IGCCs to date has been slow. Better designs, models, incorporation of lessons learned would all help. Ongoing RD&D continues to provide significant advances in the base technologies, as well as in the suite of technologies used to integrate them into an IGCC generating facility.

The emissions of air pollutants and greenhouse gases from an IGCC are less than a conventional pulverized coal plant (though latest designs make this difference smaller). The IGCC design uses less water than a conventional coal plant since a great deal of power comes from the gas turbine. The pre-cleaning of primary pollutants prior to combustion in the gas turbine allows possible later capture of CO_2 from a concentrated high-pressure gas requiring relatively low energy use.

IGCC plants (like PC plants) do not capture CO_2 without substantial plant modifications, energy losses, and investments in additional process equipment. No one is currently capturing CO_2 at full scale from IGCC plants that generate electricity from coal. CO_2 separation processes suitable for IGCC plants are used commercially in the oil and gas and chemical industries at a scale close to that ultimately needed, but their application requires the addition of more processing equipment to an IGCC plant and the deployment of gas turbines that can burn nearly pure hydrogen.

The electricity cost premium for including CO_2 capture in IGCC plants, along with drying, compression, transportation, and storage, is about 40–50 percent. Although this is a lower cost increase in percentage terms than that for conventional PC plants, IGCC plants initially cost more than PC plants. Thus, the bottom-line cost to consumers for power from IGCC plants with capture using today's technology is likely to be comparable to that for PC plants with capture (the actual relative competitiveness depends on coal moisture content and other factors as described below). However, the magnitude of these impacts could likely be reduced substantially through aggressive investments in R&D.

The CO_2 capture cost premiums listed above vary in real-world applications, depending on available coals and their physical-chemical properties, desired plant size, the CO_2 capture process and its degree of integration with other plant processes, plant elevation, the value of plant co-products, and other factors. Nonetheless, IGCC with CO_2 capture generally shows an economic advantage in studies based on low-moisture bituminous coals. For coals with high moisture and low heating value, such as subbituminous and lignite coals, an EPRI study shows PC with CO_2 capture being competitive with or having an advantage over IGCC.[1] EPRI stresses that no single advanced coal generating technology (or any generating technology) has clear-cut economic advantages across the range of U.S. applications. The best strategy for meeting future electricity needs in an economic and environmentally sustainable way lies in developing multiple technologies from which power producers (and their regulators) can choose the one best suited to local conditions and preferences. EPRI strongly recommends that policies reflect a portfolio approach that enables commercial incorporation of CCS into multiple advanced coal power technologies.

[1] *Feasibility Study for an Integrated Gasification Combined Cycle Facility at a Texas Site,* EPRI report 1014510, October 2006.

The key to proving CCS capability is the demonstration of CCS at large-scale (on the order of 1 million tons CO_2/year) for both pre- and post-combustion capture with storage in a variety of geologies. Large combined capture and storage demonstrations should be encouraged in different regions and with different coals and technologies.

Advanced Coal Generation With CO_2 Capture and Storage

Through the development and deployment of advanced coal plants with integrated CO_2 capture and storage (CCS) technologies, coal power can become part of the solution to satisfying both our energy needs and our global climate change concerns. However, a sustained RD&D program at heightened levels of investment and the resolution of legal and regulatory unknowns for long-term geologic CO_2 storage will be required to achieve the promise of advanced coal with CCS technologies. The members of EPRI's *CoalFleet for Tomorrow®* program—a research collaborative comprising more than 60 organizations representing U.S. utilities, international power generators, equipment suppliers, government research organizations, coal and oil companies, and a railroad—see crucial roles for both industry and governments worldwide in aggressively pursuing collaborative RD&D over the next 20+ years to create a full portfolio of commercially self-sustaining, competitive advanced coal power generation and CCS technologies.

Key Points:

- Advanced coal power plant technologies with integrated CO_2 capture and storage (CCS) will be crucial to lowering U.S. electric power sector CO_2 emissions. They will also be crucial to substantially lowering global CO_2 emissions.
- The availability of advanced coal power and integrated CCS and other technologies could dramatically reduce the projected increases in the cost of wholesale electricity under a carbon cap.
- It is important to avoid choosing between coal technology options. We should foster a full portfolio of technologies.
- While there are well-proven methods for capturing CO_2 resulting from coal gasification, no IGCC plant captures CO_2. IGCC technology is still relatively new and in need of more commercial installations.
- PC technology is already well proven commercially in the power industry, although potential for significant improvement exists; the need is for demonstration of post combustion capture at a commercial and affordable scale.
- There will inevitably be additional costs associated with CCS. EPRI's latest estimates suggest that the levelized cost of electricity (COE) from new coal plants (IGCC or supercritical PC) designed for capture, compression, transportation and storage of the CO_2 will be 40–80 percent higher than the COE of a conventional supercritical PC (SCPC) plant.
- EPRI's technical assessment work indicates that the preferred technology and the additional cost of electricity for CCS will depend on the coal type, location and the technology employed. Without CCS, SCPC has an advantage over IGCC. However, the additional CCS cost is generally lower with IGCC than for SCPC.
- Some studies show an advantage for IGCC with CCS with bituminous coal. With lignite coal, SCPC with CCS is generally preferred. With sub-bituminous coal, SCPC with CCS and IGCC with CCS appear to show similar costs.
- Our initial work with post-combustion CO_2 capture technologies suggests we can potentially reduce the current estimated 30 percent energy penalty associated with CCS to about 15 percent over the longer-term. Improvements in IGCC plants offer a comparable potential for reducing the cost and energy penalty as well.
- The key to proving CCS capability is the demonstration of CCS at large-scale (*i.e.,* on the order of 1 million tons CO_2/year) for both pre- and post-combustion capture and oxy-combustion with storage in a variety of geologies. Large combined capture and storage demonstrations should be encouraged in different regions and with different coals and technologies.
- EPRI's *CoalFleet for Tomorrow®* program has identified the RD&D pathways to demonstrate, by 2025, a full portfolio of economically attractive, commercial-scale advanced coal power and integrated CCS technologies suitable for use with the broad range of U.S. coal types. EPRI is currently developing collaborations to develop and demonstrate a series of IGCC and post combustion capture processes to improve the cost and energy use of integrated gasification plus capture and post combustion technologies. Some technologies will be ready for some

fuels sooner, but the economic benefits of competition are not achieved until the full portfolio is developed.

- The identified RD&D is estimated to cost $8 billion between now and 2017 and $17 billion cumulatively by 2025, and we need to begin immediately to ensure that these climate change solution technologies will be fully tested at scale by 2025.
- Major non-technical barriers associated with CO_2 storage need to be addressed before CCS can become a commercial reality, including resolution of regulatory and long-term liability uncertainties.

The Role of Advanced Coal Generation With CO_2 Capture and Storage in a Carbon-Constrained Future

Coal currently provides over half of the electricity used in the United States, and most forecasts of future energy use in the United States show that coal will continue to have a dominant share in our electric power generation for the foreseeable future. Coal is a stably priced, affordable, domestic fuel that can be used in an environmentally responsible manner. Through development of advanced pollution control technologies and sensible regulatory programs, emissions of criteria air pollutants from new coal-fired power plants have been reduced by more than 90 percent over the past three decades. And by displacing otherwise needed imports of natural gas or fuel oil, coal helps address America's energy security and reduces our trade deficit with respect to energy.

EPRI's "Electricity Technology in a Carbon-Constrained Future" study suggests that it is technically feasible to reduce U.S. electric sector CO_2 emissions by 25–30 percent relative to current emissions by 2030 while meeting the increased demand for electricity. The study showed that the largest single contributor to emissions reduction would come from the integration of CCS technologies with advanced coal-based power plants coming on-line after 2020.

Economic analyses of scenarios to achieve the study's emission reduction goals show that in 2050, a U.S. electricity generation mix based on a full portfolio of technologies, including advanced coal technologies with integrated CCS and advanced light water nuclear reactors, results in wholesale electricity prices at less than half of the wholesale electricity price for a generation mix without advanced coal/CCS and nuclear power. In the case with advanced coal/CCS and nuclear power, the cost to the U.S. economy of a CO_2 emissions reduction policy is $1 trillion less than in the case without advanced coal/CCS and nuclear power, with a much stronger manufacturing sector. Both of these analyses are documented in the 2007 EPRI Summer Seminar Discussion paper, "The Power to Reduce CO_2 Emissions—the Full Portfolio," available at *http://epri-reports.org/DiscussionPaper2007.pdf*.

Accelerating RD&D on Advanced Coal Technologies With CO_2 Capture and Storage—Investment and Time Requirements

The portfolio aspect of advanced coal with integrated CCS technologies must be emphasized because no single advanced coal technology (or any generating technology) has clear-cut economic advantages across the range of U.S. applications. The best strategy for meeting future electricity needs while addressing climate change concerns and minimizing economic disruption lies in developing a *full portfolio* of technologies from which power producers (and their regulators) can choose the option best suited to local conditions and preferences and provide power at the lowest cost to the customer. Toward this end, four major technology efforts related to CO_2 emissions reduction from coal-based power systems must be undertaken:

1. Increased efficiency and reliability of IGCC power plants
2. Increased thermodynamic efficiency of PC power plants
3. Improved technologies for capture of CO_2 from coal combustion- and gasification-based power plants
4. Reliable, acceptable technologies for long-term storage of captured CO_2

Identification of mechanisms to share RD&D financial and technical risks and to address legal and regulatory uncertainties must take place as well.

In short, a comprehensive recognition of all the factors needed to hasten deployment of competitive, commercial advanced coal and integrated CO_2 capture and storage technologies—and implementation of realistic, pragmatic plans to overcome barriers—is the key to meeting the challenge to supply affordable, environmentally responsible energy in a carbon-constrained world.

A typical path to develop a technology to commercial maturity consists of moving from the conceptual stage to laboratory testing, to small pilot-scale tests, to larger-scale tests, to multiple full-scale demonstrations, and finally to deployment in full-scale commercial operations. For capital-intensive technologies such as advanced coal power systems, each stage can take years or even a decade to complete, and each sequential stage entails increasing levels of investment. As depicted in Figure 1, several key advanced coal power and CCS technologies are now in (or approaching) an "adolescent" stage of development. This is a time of particular vulnerability in the technology development cycle, as it is common for the expected costs of full-scale application to be higher than earlier estimates when less was known about scale-up and application challenges. Public agency and private funders can become disillusioned with a technology development effort at this point, but as long as fundamental technology performance results continue to meet expectations, and a path to cost reduction is clear, perseverance by project sponsors in maintaining momentum is crucial.

Unexpectedly high costs at the mid-stage of technology development have historically come down following market introduction, experience gained from "learning-by-doing," realization of economies of scale in design and production as order volumes rise, and removal of contingencies covering uncertainties and first-of-a-kind costs. An International Energy Agency study led by Carnegie Mellon University (CMU) observed this pattern of cost-reduction-over-time for power plant environmental controls, and CMU predicts a similar reduction in the cost of power plant CO_2 capture technologies as the cumulative installed capacity grows.[2] EPRI concurs with their expectations of experience-based cost reductions and believes that RD&D on specifically identified technology refinements can lead to greater cost reductions sooner in the deployment phase.

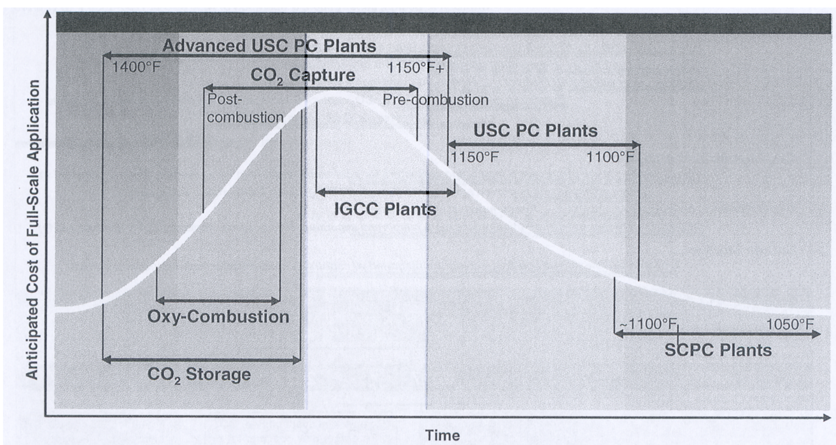


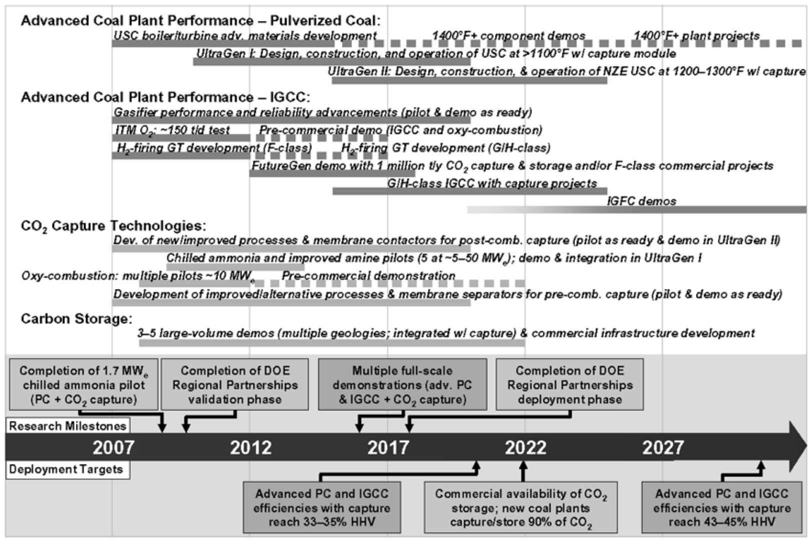
Figure 1 – Model of the development status of major advanced coal and CO_2 capture and storage technologies (temperatures shown for pulverized coal technologies are turbine inlet steam temperatures)

Of the coal-based power generating and carbon sequestration technologies shown in Figure 1, only SCPC technology has reached commercial maturity. It is crucial that other technologies in the portfolio—namely ultra-supercritical (USC) PC, IGCC, CO_2 capture (pre-combustion, post-combustion, and oxy-combustion), and CO_2 storage—be given sufficient support to reach the stage of declining constant dollar costs *before* society's requirements for greenhouse gas reductions compel their application in large numbers.

Figure 2 depicts the major activities in each of the four technology areas that must take place to achieve a robust set of integral advanced coal/CCS solutions. Please note that UltraGen III is not included in Figure 2 but the schedule for "Design, construction & operation of NZE USC PC at up to 1,400 °F w/capture" is expected to commence around 2020. Important, but not shown in the figure, are the interactions between RD&D activities. For example, the ion transport membrane (ITM) oxygen supply technology shown under IGCC may also be able to be applied to oxy-combustion PC units. Further, while the individual goals related to efficiency, CO_2 capture, and CO_2 storage present major challenges, significant challenges also

[2] IEA Greenhouse Gas R&D Programme (IEA GHG), "Estimating Future Trends in the Cost of CO_2 Capture Technologies," 2006/5, January 2006.

arise from complex interactions that occur when CO_2 capture processes are integrated with gasification- and combustion-based power plant processes.



Source: The Power to Reduce CO_2 Emissions – the Full Portfolio," http://epri-reports.org/DiscussionPaper2007.pdf

Figure 2 – Timing of advanced coal power system and CO_2 capture and storage RD&D activities and milestones

Reducing CO_2 Emissions Through Improved Coal Power Plant Efficiency—A Key Companion to CCS That Lowers Cost and Energy Requirements

Improved thermodynamic efficiency reduces CO_2 emissions by reducing the amount of fuel required to generate a given amount of electricity. A two-percentage point gain in efficiency provides a reduction in fuel consumption of roughly 5 percent and a similar reduction in flue gas and CO_2 output. Because the size and cost of CO_2 capture equipment is determined by the volume of flue gas to be treated, higher power block efficiency reduces the capital and energy requirements for CCS. Depending on the technology used, improved efficiency can also provide similar reductions in criteria air pollutants, hazardous air pollutants, and water consumption.

A typical baseloaded 500 MW (net) coal plant emits about 3 million metric tons of CO_2 per year. Individual plant emissions vary considerably given differences in plant steam cycle, coal type, capacity factor, and operating regimes. For a given fuel, however, a new supercritical PC unit built today might produce 5–10 percent less CO_2 per megawatt-hour (MWh) than the existing fleet average for that coal type.

With an aggressive RD&D program on efficiency improvement, new USC PC plants could reduce CO_2 emissions per MWh by up to 25 percent relative to the existing fleet average. Significant efficiency gains are also possible for IGCC plants by employing advanced gas turbines and through more energy-efficient oxygen plants and synthesis (fuel) gas cleanup technologies.

EPRI and the Coal Utilization Research Council (CURC), in consultation with DOE, have identified a challenging but achievable set of milestones for improvements in the efficiency, cost, and emissions of PC and coal-based IGCC plants. The EPRI–CURC Roadmap projects an overall improvement in the thermal efficiency of state-of-the art generating technology from 38–41 percent in 2010 to 44–49 percent by 2025 (on a higher heating value [HHV] basis; see Table 1). As Table 1 indicates, power-block efficiency gains (*i.e.,* without capture systems) will be offset by the energy required for CO_2 capture, but as noted, they are important in reducing the overall cost of CCS. Coupled with opportunities for major improvements in the energy efficiency of CO_2 capture processes per se, aggressive pursuit of the EPRI–CURC RD&D program offers the prospect of coal power plants *with* CO_2 capture in 2025 that have net efficiencies meeting or exceeding current-day power plants without CO_2 capture.

It is also important to note that the numeric ranges in Table 1 are not simply a reflection of uncertainty, but rather they underscore an important point about differences among U.S. coals. The natural variations in moisture and ash content and combustion characteristics between coals have a significant impact on attainable efficiency. An advanced coal plant firing Wyoming and Montana's Powder River Basin (PRB) coal, for example, would likely have an HHV efficiency 2 percentage points lower than the efficiency of a comparable plant firing Appalachian bituminous coals. Equally advanced plants firing lignite would ikely have efficiencies 2 percentage points lower than their counterparts firing PRB. Any government incentive program with an efficiency-based qualification criterion should recognize these inherent differences in the attainable efficiencies for plants using different ranks of coal.

Table 1.—Efficiency Milestones in EPRI-CURC Roadmap

	2010	2015	2020	2025
PC & IGCC Systems (*Without CO_2 Capture*)	38–41% HHV	39–43% HHV	42–46% HHV	44–49% HHV
PC & IGCC Systems (*With CO_2 Capture**)	31–32% HHV	31–35% HHV	33–39% HHV	39–46% HHV

**Efficiency values reflect impact of 90 percent CO_2 capture, but not compression or transportation.*

New Plant Efficiency Improvements—IGCC

Although IGCC is not yet a mature technology for coal-fired power plants, chemical plants around the world have accumulated a 100-year experience base operating coal-based gasification units and related gas cleanup processes. The most advanced of these units are similar to the front end of a modern IGCC facility. Similarly, several decades of experience firing natural gas and petroleum distillate have established a high level of maturity for the basic combined cycle generating technology. Nonetheless, ongoing RD&D continues to provide significant advances in the base technologies, as well as in the suite of technologies used to integrate them into an IGCC generating facility.

Efficiency gains in currently proposed IGCC plants will come from the use of new "FB-class" gas turbines, which will provide an overall plant efficiency gain of about 0.6 percentage point (relative to IGCC units with FA-class models, such as Tampa Electric's Polk Power Station). This corresponds to a decrease in the rate of CO_2 emissions per MWh of about 1.5 percent. Alternatively, this means 1.5 percent less fuel is required per MWh of output, and thus the required size of pre-combustion water-gas shift and CO_2 separation equipment would be slightly smaller.

Figure 3 depicts the anticipated time-frame for further developments identified by EPRI's *CoalFleet for Tomorrow®* program that promise a succession of significant improvements in IGCC unit efficiency. Key technology advances under development include:

- larger capacity gasifiers (often via higher operating pressures that boost throughput without a commensurate increase in vessel size)
- integration of new gasifiers with larger, more efficient G- and H-class gas turbines
- use of ion transport membrane or other more energy-efficient technologies in oxygen plants
- warm synthesis gas cleanup and membrane separation processes for CO_2 capture that reduce energy losses in these areas
- recycle of liquefied CO_2 to replace water in gasifier feed slurry (reducing heat loss to water evaporation)
- hybrid combined cycles using fuel cells to achieve generating efficiencies exceeding those of conventional combined cycle technology

Improvements in gasifier reliability and in control systems also contribute to improved annual average efficiency by minimizing the number and duration of startups and shutdowns.

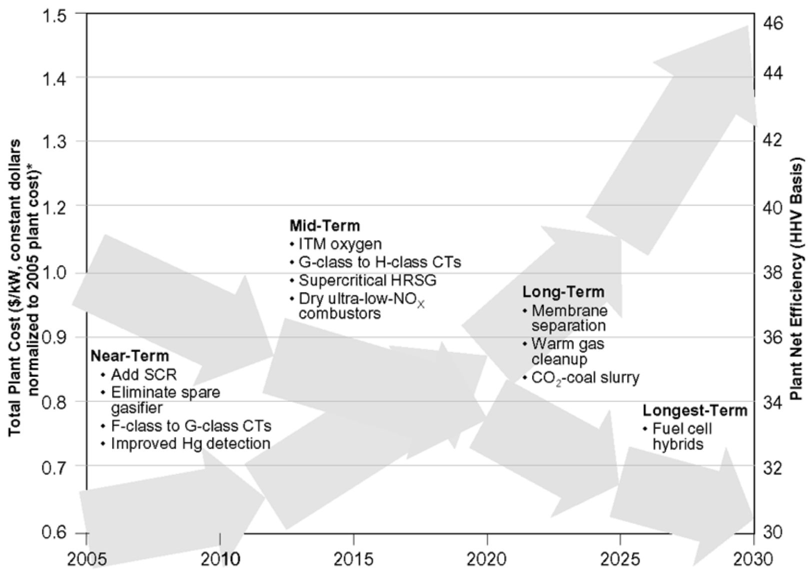


Figure 3 – RD&D path for capital cost reduction (falling arrows) and efficiency improvement (rising arrows) for IGCC power plants with 90% CO_2 capture

* *For a slurry-fed gasifier designed for 90% unit availability and 90% pre-combustion CO_2 capture using Pittsburgh #8 bituminous coal; cost normalization using Chemical Engineering Plant Cost Index or equivalent. A similar trend is observed in analyses of dry-fed gasifiers using Power River Basin subbituminous coal, although the absolute values vary somewhat from those shown.*

Counteracting Gas Turbine Output Loss at High Elevations. IGCC plants designed for application in high-elevation locations must account for the natural reduction in gas turbine power output that occurs where the air is thin. This phenomenon is rooted in the fundamental volumetric flow limitation of a gas turbine, and can reduce power output by up to 15 percent at an elevation of 5,000 feet (relative to a comparable plant at sea level). EPRI is exploring measures to counteract this power loss, including inlet air chilling (a technique used at natural gas power plants to mitigate the power loss that comes from thinning of the air on a hot day) and use of supplemental burners between the gas turbine and steam turbine to boost the plant's steam turbine section generating capacity.

Larger, Higher Firing Temperature Gas Turbines. For plants coming on-line around 2015, the larger size G-class gas turbines, which operate at higher firing temperatures (relative to F-class machines) can improve efficiency by 1 to 2 percentage points while also decreasing capital cost per kW capacity. The H-class gas turbines coming on-line in the same timeframe, which also feature higher firing temperatures as well as steam-based internal cooling of hot turbine components, will provide a further increase in efficiency and capacity.

Ion Transport Membrane-Based Oxygen Plants. Most gasifiers used in IGCC plants require a large quantity of high-pressure, high purity oxygen, which is typically generated onsite with an expensive and energy-intensive cryogenic process. The ITM process allows the oxygen in high-temperature air to pass through a membrane while preventing passage of non-oxygen atoms. According to developers, an ITM-based oxygen plant consumes 35–60 percent less power and costs 35 percent less than a cryogenic plant. DOE has been supporting development of this technology. EPRI is performing a due diligence assessment of this technology in advance of potential participation in technology scale-up efforts and is planning to solicit an industry consortium to support development.

Supercritical Heat Recovery Steam Generators. In IGCC plants, hot exhaust gas exiting the gas turbine is ducted into a heat exchanger known as a heat recovery steam generator (HRSG) to transfer energy into water-filled tubes producing steam to drive a steam turbine. This combination of a gas turbine and steam turbine power cycles produces electricity more efficiently than either a gas turbine or steam turbine alone. As with conventional steam power plants, the efficiency of the steam cycle in a combined cycle plant increases when turbine inlet steam temperature and pressure are increased. The higher exhaust temperatures of G- and H-class gas turbines offer the potential for adoption of more-efficient supercritical steam cycles. Materials for use in a supercritical HRSG are generally established, and thus should not pose a barrier to technology implementation once G- and H-class gas turbines become the standard for IGCC designs.

Synthesis Gas Cleaning at Higher Temperatures. The acid gas recovery (AGR) processes currently used to remove sulfur compounds from synthesis gas require that the gas and solvent be cooled to about 100 °F, thereby causing a loss in efficiency. Further costs and efficiency loss are inherent in the process equipment and auxiliary steam required to recover the sulfur compounds from the solvent and convert them to useable products. Several DOE-sponsored RD&D efforts aim to reduce the energy losses and costs imposed by this recovery process. These technologies (described below) could be ready—with adequate RD&D support—by 2020:

- The Selective Catalytic Oxidation of Hydrogen Sulfide process eliminates the Claus and Tail Gas Treating units, along with the traditional solvent-based AGR contactor, regenerator, and heat exchangers, by directly converting hydrogen sulfide (H_2S) to elemental sulfur. The process allows for a higher operating temperature of approximately 300 °F, which eliminates part of the low-temperature gas cooling train. The anticipated benefit is a net capital cost reduction of about $60/kW along with an efficiency gain of about 0.8 percentage point.
- The RTI/Eastman High-Temperature Desulfurization System uses a regenerable dry zinc oxide sorbent in a dual loop transport reactor system to convert H_2S and COS to H_2O, CO_2, and SO_2. Tests at Eastman Chemical Company have shown sulfur species removal rates above 99.9 percent, with 10 ppm output versus 8,000+ ppm input sulfur, using operating temperatures of 800–1,000 °F. This process is also being tested for its ability to provide a high-pressure CO_2 by-product. The anticipated benefit for IGCC, compared with using a standard oil-industry process for sulfur removal, is a net capital cost reduction of $60–$90 per kW, a thermal efficiency gain of 2–4 percent for the gasification process, and a slight reduction in operating cost. Tests are also under way for a multi-contaminant removal processes that can be integrated with the transport desulfurization system at temperatures above 480 °F.

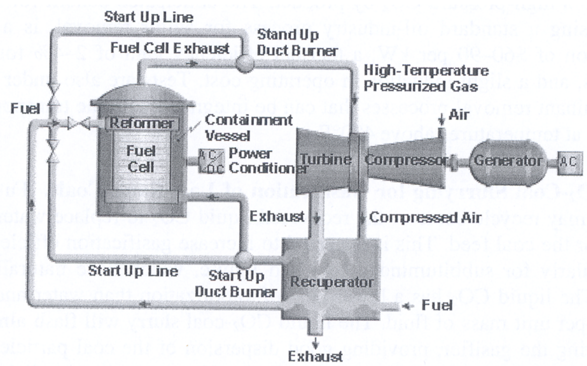
Liquid CO_2-Coal Slurrying for Gasification of Low-Rank Coals. Future IGCC plants with CCS may recycle some of the recovered liquid CO_2 to replace water as the slurrying medium for the coal feed. This is expected to increase gasification efficiency for all coals, but particularly for subbituminous coal and lignite, which have naturally high moisture contents. The liquid CO_2 has a lower heat of vaporization than water and is able to carry more coal per unit mass of fluid. The liquid CO_2-coal slurry will flash almost immediately upon entering the gasifier, providing good dispersion of the coal particles and potentially yielding the higher performance of a dry-fed gasifier with the simplicity of a slurry-fed system.

Traditionally, slurry-fed gasification technologies have a cost advantage over conventional dry-fed fuel handling systems, but they suffer a large performance penalty when used with coals containing a large fraction of water and ash. EPRI identified CO_2 coal slurrying as an innovative fuel preparation concept 20 years ago, when IGCC technology was in its infancy. At that time, however, the cost of producing liquid CO_2 was too high to justify the improved thermodynamic performance. Requirements for CCS change that, as it will substantially reduce the incremental cost of producing a liquid CO_2 stream.

To date, CO_2-coal slurrying has only been demonstrated at pilot scale and has yet to be assessed in feeding coal to a gasifier, so the estimated performance benefits remain to be confirmed. It will first be necessary, however, to update previous studies to quantify the potential benefit of liquid CO_2 slurries with IGCC plants designed for CO_2 capture. If the predicted benefit is economically advantageous, a significant amount of scale-up and demonstration work would be required to qualify this technology for commercial use.

Fuel Cells and IGCC. No matter how far gasification and turbine technologies advance, IGCC power plant efficiency will never progress beyond the inherent thermodynamic limits of the gas turbine and steam turbine power cycles (along with lower limits imposed by available materials technology). Several IGCC-fuel cell hybrid power plant concepts (IGFC) aim to provide a path to coal-based power generation with net efficiencies that exceed those of conventional combined cycle generation.

Along with its high thermal efficiency, the fuel cell hybrid cycle reduces the energy consumption for CO_2 capture. The anode section of the fuel cell produces a stream that is highly concentrated in CO_2. After removal of water, this stream can be compressed for sequestration. The concentrated CO_2 stream is produced without having to include a water-gas shift reactor in the process (see Figure 4). This further improves the thermal efficiency and decreases capital cost. IGFC power systems are a long-term solution, however, and are unlikely to see full-scale demonstration until about 2030.



Source: U.S. Department of Energy; http://www.netl.doe.gov/technologies/coalpower/fuelcells/hybrids.html

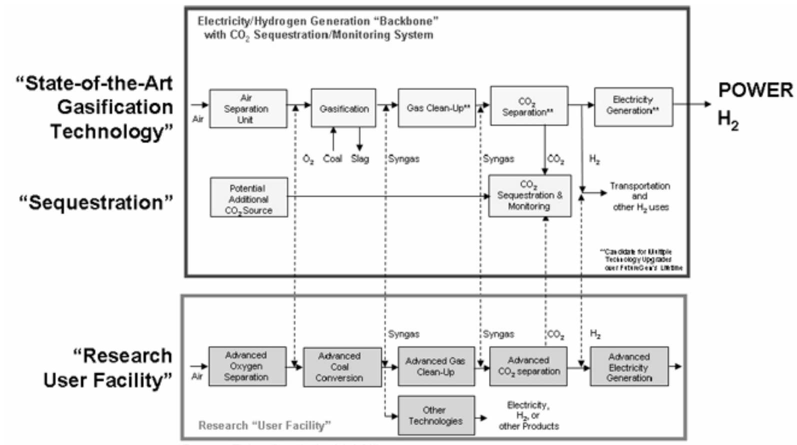
Figure 4 – Schematic of fuel cell-turbine hybrid

The Changing Role of FutureGen. In January of this year, DOE announced a restructured approach to the FutureGen project. Previously, the FutureGen Industrial Alliance and DOE were intending to build a first-of-its-kind, near-zero emissions coal-fed IGCC power plant integrated with CCS. The commencement of full-scale operations was targeted for 2013. The project aimed at storing CO_2 in a representative geologic formation at a rate of at least one million metric tons per year. DOE had committed to spend $1.1 billion in support of the project while the FutureGen Industrial Alliance had agreed to contribute $400 million.

Under its revised approach, DOE will offer to pay the additional cost of capturing CO_2 at multiple IGCC plants. Each plant would capture and store at least 1 million tons of CO_2 per year. DOE's goal is to have the plants in operation between 2015 and 2016.

The original FutureGen concept was meant to serve as a "living laboratory" for testing advanced technologies that offered the promise of clean environmental performance at a reduced cost and increased reliability. The original FutureGen concept, as shown in Figure 5 was to have the flexibility to conduct full-scale and slipstream tests of such scalable advanced technologies as:

- Membrane processes to replace cryogenic separation for oxygen production
- An advanced transport reactor sidestream with 30 percent of the capacity of the main gasifier
- Advanced membrane and solvent processes for H_2 and CO_2 separation
- A raw gas shift reactor that reduces the upstream clean-up requirements
- Ultra-low-NO_X combustors that can be used with high-hydrogen synthesis gas
- A fuel cell hybrid combined cycle pilot
- Smart dynamic plant controls including a CO_2 management system



Source: FutureGen Industrial Alliance

Figure 5 – FutureGen technology platforms

While the revised DOE FutureGen concept will meet the original goal of having a CCS test of at least 1 million tons of CO_2 per year (albeit two to 3 years later than the original target), the other original goal of also hosting the development of several advanced technologies for decreasing plant costs appears to have been dropped.

EPRI has responded to DOE's RFI on the revised FutureGen concept. We asked for clarification on what aspects of the costs of including CO_2 capture and storage (CCS) would be covered, and we gave our estimate of what the total costs would be for including CCS on one train of a two-train 600 MW IGCC. We also highlighted the other major RD&D activities that are needed for improving the efficiency and cost of IGCC technologies with CO_2 capture (see Figure 6). In addition, we asked whether non-IGCC coal power plants which capture at least 1 million tons of CO_2 per year could qualify for funding under the revised FutureGen concept. For example, would the incremental CCS costs of a project such as our proposed UltraGen advanced SCPC plant with post-combustion capture and geological storage of CO_2 be eligible for DOE support under the restructured FutureGen concept.

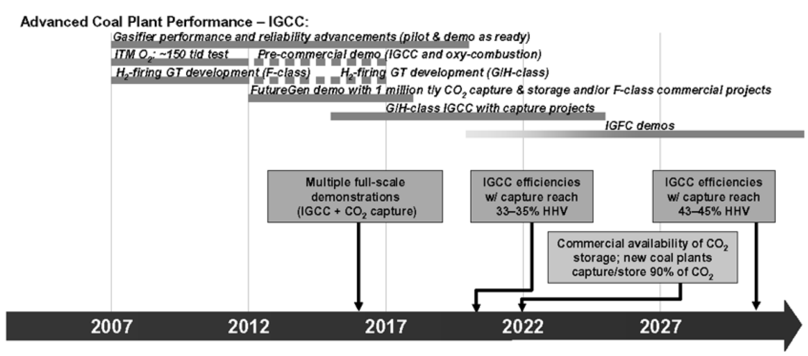


Figure 6 – Timing of advanced IGCC and CO_2 capture integration RD&D activities and milestones

New Plant Efficiency Improvements—Advanced Pulverized Coal

Pulverized-coal power plants have long been a primary source of reliable and affordable power in the United States and around the world. The advanced level of maturity of the technology, along with basic thermodynamic principles, suggests that significant efficiency gains can most readily be realized by increasing the operating temperatures and pressures of the steam cycle. Such increases, in turn, can be achieved only if there is adequate development of suitable materials and new boiler and steam turbine designs that allow use of higher steam temperatures and pressures.

Current state-of-the-art plants use supercritical main steam conditions (*i.e.,* temperature and pressure above the "critical point" where the liquid and vapor phases of water are indistinguishable). SCPC plants typically have main steam conditions up to 1,100 °F. The term "ultra-supercritical" is used to describe plants with main steam temperatures in excess of 1,100 °F and potentially as high as 1,400 °F.

Achieving higher steam temperatures and higher efficiency will require the development of new corrosion-resistant, high-temperature nickel alloys for use in the boiler and steam turbine. In the United States, these challenges are being address by the Ultra-Supercritical Materials Consortium, a DOE R&D program involving Energy Industries of Ohio, EPRI, the Ohio Coal Development Office, and numerous equipment suppliers. EPRI provides technical management for the Consortium. Results are applicable to all ranks of coal. As noted, higher power block efficiencies translate to lower costs for post-combustion CO_2 capture equipment.

It is expected that a USC PC plant operating at about 1,300 °F will be built during the next seven to 10 years, following the demonstration and commercial availability of advanced materials from these programs. This plant would achieve an efficiency (before installation of CO_2 capture equipment) of about 45 percent (HHV) on bituminous coal, compared with 39 percent for a current state-of-the-art plant, and would reduce CO_2 production per net MWh by about 15 percent.

Ultimately, nickel-base alloys are expected to enable stream temperatures in the neighborhood of 1,400 °F and pre-capture generating efficiencies up to 47 percent HHV with bituminous coal. This approximately 10 percentage point improvement over the efficiency of a new subcritical pulverized-coal plant would equate to a decrease of about 25 percent in CO_2 and other emissions per MWh. The resulting saving in the cost of subsequently installed CO_2 capture equipment is substantial.

Figure 7 illustrates a timeline developed by EPRI's *CoalFleet for Tomorrow®* program to establish efficiency improvement and cost reduction goals for USC PC plants with CO_2 capture.

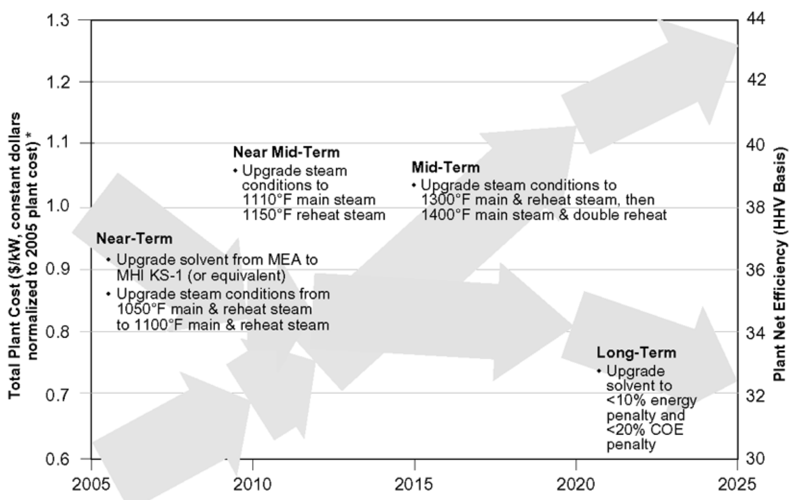


Figure 7 – RD&D path for capital cost reduction (falling arrows) and efficiency improvement (rising arrows) for PC power plants with 90% CO_2 capture

** For a unit designed for 90% unit availability and 90% post-combustion CO_2 capture firing a Pittsburgh #8 bituminous coal; cost normalization using Chemical Engineering Plant Cost Index or equivalent. A similar trend is observed in analyses of PC units with CCS using other U.S. coals, although the efficiency values are up to two percentage points lower for units firing subbituminous coal such as Powder River Basin and up to four percentage points lower for units firing lignite.*

UltraGen Ultrasupercritical (USC) Pulverized Coal (PC) Commercial Projects. EPRI and industry representatives have proposed a program to support commercial projects that demonstrate advanced PC and CCS technologies. The vision entails construction of two (or more) commercially operated USC PC power plants that combine state-of-the-art pollution controls, ultra-supercritical steam power cycles, and innovative CO_2 capture technologies.

The UltraGen I plant will use the best of today's proven ferritic steels in high-temperature boiler and steam turbine components, while UltraGen II will be the first plant in the United States to feature nickel-based alloys and is designed for steam temperatures up to 1,300 °F. UltraGen III will be designed for steam temperatures up to 1,400 °F using materials currently under development by the DOE boiler and steam turbine materials program.

UltraGen I will demonstrate CO_2 capture modules that separate about 1 million tons CO_2/yr using the best-established technology. This system will be about 6 times the size of the largest CO_2 capture system operating on a coal-fired boiler today, and will be integrated into the thermal cycle of the boiler to minimize parasitic loads and capacity loss. UltraGen II will at least double the size of the UltraGen I CO_2 capture system, and may demonstrate a new class of chemical solvent if one of the emerging low-regeneration-energy processes has reached a sufficient stage of development. UltraGen III is expected to capture up to 90 percent of the CO_2, 3.5 times more than for UltraGen I. All three plants will demonstrate ultra-low emissions, and dry and compress the captured CO_2 to demonstrate long-term geologic storage and/or use in enhanced oil or gas recovery operations. Figure 8 depicts the proposed key features of UltraGen I, II, and III.

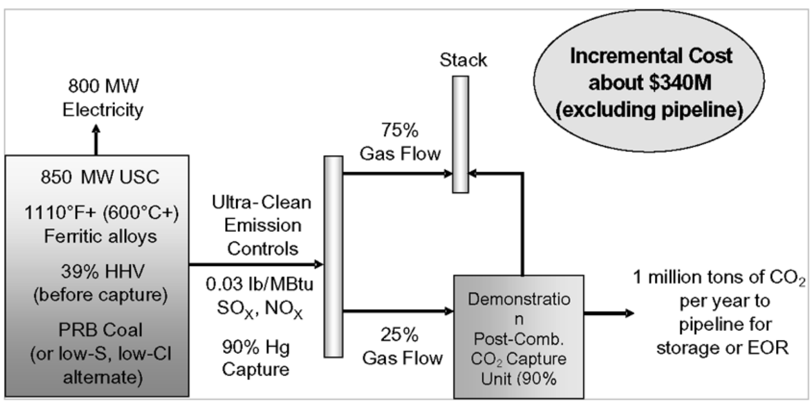


Figure 8 – Key parameters for UltraGen I, assuming a subbituminous feed coal such as Powder River Basin

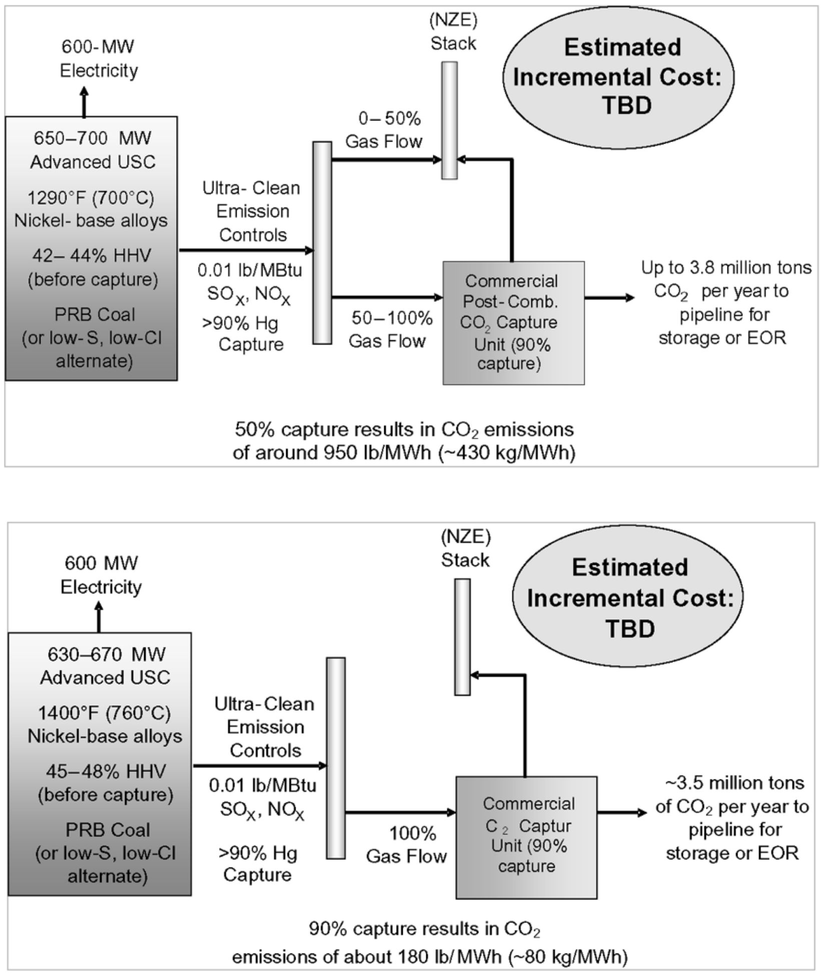


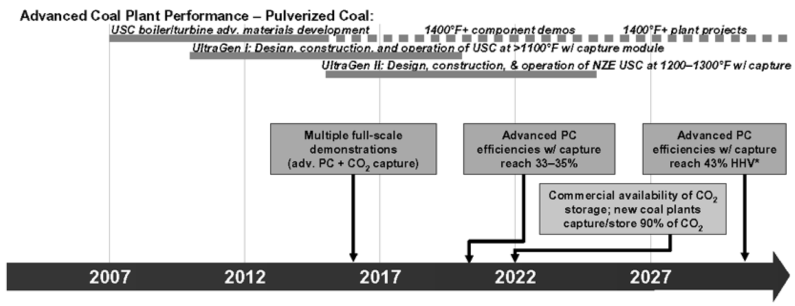
Figure 8 – Key parameters for UltraGen II (upper schematic) and UltraGen III (lower schematic), assuming a subbituminous feed coal such as Powder River Basin

To provide a platform for testing and developing emerging PC and CCS technologies, the UltraGen program will allow for technology trials at existing sites as well as at the sites of new projects. Unlike FutureGen, EPRI expects the UltraGen projects will be commercially dispatched by electricity grid operators. If the FutureGen concept could accommodate post combustion capture the differential cost of UltraGen CCS could be part of the full portfolio of projects. The differential cost to the host company for demonstrating these improved features are envisioned to be offset by any available tax credits (or other incentives) and by funds raised through an industry-led consortium formed by EPRI.

The UltraGen projects represent the type of "giant step" collaborative efforts that need to be taken to advance integrated PC/CCS technology to the next phase of evolution and assure competitiveness in a carbon-constrained world. Because of the time and expense for each "design and build" iteration for coal power plants (3 to 5 years not counting the permitting process and ~$2 billion), there is no room for hesitation in terms of commitment to advanced technology validation and demonstration projects. EPRI is currently discussing the UltraGen project concept with several firms in the U.S. and internationally, and plans to develop a consortium to support demonstration of the technology.

The UltraGen projects will resolve technical and economic barriers to the deployment of USC PC and CCS technology by providing a shared-risk vehicle for testing and validating high-temperature materials, components, and designs in plants also providing superior environmental performance.

Figure 9 summarizes EPRI's recommended major RD&D activities for improving the efficiency and cost of USC PC technologies with CO_2 capture. Please note that UltraGen III is not included in Figure 9 but the schedule for "Design, construction & operation of NZE USC PC at up to 1,400 °F w/capture" is expected to commence around 2020.



*for bituminous coal; equally advanced PC plants firing subbituminous coal and lignite will have efficiencies two to four percentage points lower due to higher moisture and ash contents

Figure 9 – Timing of advanced PC and CO_2 capture integration RD&D activities and milestones

Efficiency Improvement and CCS Retrofits for the Existing PC Fleet. It would be economically advantageous to operate the many reliable subcritical PC units in the U.S. fleet well into the future. Premature replacement of these units or mandatory retrofit of these units for CO_2 capture en masse would be economically prohibitive. Their flexibility for load following and provision of support services to ensure grid stability makes them highly valuable. With equipment upgrades, many of these units can realize modest efficiency gains, which, when accumulated across the existing generating fleet could make a sizable reduction in CO_2 emissions. For some existing plants, retrofit of CCS will make sense, but specific plant design features, space limitations, and economic and regulatory considerations must be carefully analyzed to determine whether retrofit-for-capture is feasible.

These upgrades depend on the equipment configuration and operating parameters of a particular plant and may include:

- turbine blading and steam path upgrades
- turbine control valve upgrades for more efficient regulation of steam
- cooling tower and condenser upgrades to reduce circulating water temperature, steam turbine exhaust backpressure, and auxiliary power consumption
- cooling tower heat transfer media upgrades
- condenser optimization to maximize heat transfer and minimize condenser temperature
- condenser air leakage prevention/detection
- variable speed drive technology for pump and fan motors to reduce power consumption
- air heater upgrades to increase heat recovery and reduce leakage
- advanced control systems incorporating neural nets to optimize temperature, pressure, and flow rates of fuel, air, flue gas, steam, and water
- optimization of water blowdown and blowdown energy recovery
- optimization of attemperator design, control, and operating scenarios
- sootblower optimization via "intelligent" sootblower system use
- coal drying (for plants using lignite and subbituminous coals)

Coal Drying for Increased Generating Efficiency. Boilers designed for high-moisture lignite have traditionally employed higher feed rates (lb/hr) to account for the large latent heat load to evaporate fuel moisture. An innovative concept developed by Great River Energy (GRE) and Lehigh University uses low-grade heat recovered from within the plant to dry incoming fuel to the boiler, thereby boosting plant efficiency and output. [In contrast, traditional thermal drying processes are complex and require high-grade heat to remove moisture from the coal.] Specifically, the GRE approach uses steam condenser and boiler exhaust heat exchangers to heat air and water fed to a fluidized-bed coal dryer upstream of the plant pulverizers. Based on successful tests with a pilot-scale dryer and more than a year of continuous operation with a prototype dryer at its Coal Creek station, GRE (with U.S. Department of Energy support and EPRI technical consultation) is now building a full suite of dryers for Unit 2 (*i.e.,* a commercial-scale demonstration). In addition to the efficiency and CO_2 emission reduction benefits from reducing the lignite feed moisture content by about 25 percent, the plant's air emissions will be reduced as well.[3] Application of this technology is not limited to PC units firing lignite. EPRI believes it may find application in PC units firing subbituminous coal and in IGCC units with dry-fed gasifiers using low-rank coals.

Improving CO_2 Capture Technologies

CCS entails pre-combustion or post-combustion CO_2 capture technologies, CO_2 drying and compression (and sometimes further removal of impurities), and the transportation of separated CO_2 to locations where it can be stored away from the atmosphere for centuries or longer.

Albeit at considerable cost, CO_2 capture technologies can be integrated into all coal-based power plant technologies. For both new plants and retrofits, there is a tremendous need (and opportunity) to reduce the energy required to remove CO_2 from fuel gas or flue gas. Figure 10 shows a selection of the key technology developments and test programs needed to achieve commercial CO_2 capture technologies for advanced coal combustion- and gasification-based power plants at a progressively shrinking constant-dollar levelized cost-of-electricity premium. Specifically, the target is a premium of about $6/MWh in 2025 (relative to plants at that time without capture) compared with an estimated 2010 cost premium of perhaps $40/MWh (not counting the cost of transportation and storage). Such a goal poses substantial engineering challenges and will require major investments in RD&D to roughly halve the currently large energy requirements (operating costs) associated with CO_2 solvent regeneration. Achieving this goal will allow power producers to meet the public demand for stable electricity prices while reducing CO_2 emissions to address climate change concerns.

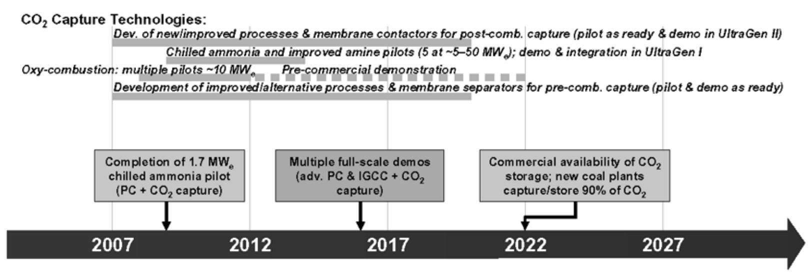


Figure 10 – Timing of CO_2 capture technology development RD&D activities and milestones

Pre-Combustion CO_2 Capture (IGCC)

IGCC technology allows for CO_2 capture to take place via an added fuel gas processing step at elevated pressure, rather than at the atmospheric pressure of post-combustion flue gas, permitting capital savings through smaller equipment sizes as well as lower operating costs.

Currently available technologies for such pre-combustion CO_2 removal use a chemical and/or physical solvent that selectively absorbs CO_2 and other "acid gases," such as hydrogen sulfide. Application of this technology requires that the CO in synthesis gas (the principal component) first be "shifted" to CO_2 and hydrogen via a catalytic reaction with water. The CO_2 in the shifted synthesis gas is then removed

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[3] C. Bullinger, M. Ness, and N. Sarunac, "One Year of Operating Experience with Prototype Fluidized Bed Coal Dryer at Coal Creek Generating Station," 32nd International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, FL, June 10–15, 2007.

via contact with the solvent in an absorber column, leaving a hydrogen-rich synthesis gas for combustion in the gas turbine. The CO_2 is released from the solvent in a regeneration process that typically reduces pressure and/or increases temperature.

Chemical plants currently employ such a process commercially using methyl diethanolamine (MDEA) as a chemical solvent or the Selexol and Rectisol processes, which rely on physical solvents. Physical solvents are generally preferred when extremely high (>99.8 percent) sulfur species removal is required. Although the required scale-up for IGCC power plant applications is less than that needed for scale-up of post-combustion CO_2 capture processes for PC plants, considerable engineering challenges remain and work on optimal integration with IGCC cycle processes has just begun.

The impact of current pre-combustion CO_2 removal processes on IGCC plant thermal efficiency and capital cost is significant. In particular, the water-gas shift reaction reduces the heating value of synthesis gas fed to the gas turbine. Because the gasifier outlet ratios of CO to methane to H_2 are different for each gasifier technology, the relative impact of the water-gas shift reactor process also varies. In general, however, it can be on the order of a 10 percent fuel energy reduction. Heat regeneration of solvents further reduces the steam available for power generation. Other solvents, which are depressurized to release captured CO_2, must be re-pressurized for reuse. Cooling water consumption is increased for solvents needing cooling after regeneration and for pre-cooling and interstage cooling during compression of separated CO_2 to a supercritical state for transportation and storage. Heat integration with other IGCC cycle processes to minimize these energy impacts is complex and is currently the subject of considerable RD&D by EPRI and others.

Membrane CO_2 Separation. Technology for separating CO_2 from shifted synthesis gas (or flue gas from PC plants) offers the promise of lower auxiliary power consumption but is currently only at the laboratory stage of development. Several organizations are pursuing different approaches to membrane-based applications. In general, however, CO_2 recovery on the low-pressure side of a selective membrane can take place at a higher pressure than is now possible with solvent processes, reducing the subsequent power demand for compressing CO_2 to a supercritical state. Membrane-based processes can also eliminate steam and power consumption for regenerating and pumping solvent, respectively, but they require power to create the pressure difference between the source gas and CO_2-rich sides. If membrane technology can be developed at scale to meet performance goals, it could enable up to a 50 percent reduction in capital cost and auxiliary power requirements relative to current CO_2 capture and compression technology.

Post-Combustion CO_2 Capture (PC and Circulating Fluidized-Bed (CFB) Plants)

The post-combustion CO_2 capture processes being discussed for power plant boilers in the near-term draw upon commercial experience with amine solvent separation at much smaller scale in the food, beverage and chemical industries, including three U.S. applications of CO_2 capture from coal-fired boilers.

These processes contact flue gas with an amine solvent in an absorber column (much like a wet SO_2 scrubber) where the CO_2 chemically reacts with the solvent. The CO_2-rich liquid mixture then passes to a stripper column where it is heated to change the chemical equilibrium point, releasing the CO_2. The "regenerated" solvent is then recirculated back to the absorber column, while the released CO_2 may be further processed before compression to a supercritical state for efficient transportation to a storage location.

After drying, the CO_2 released from the regenerator is relatively pure. However, successful CO_2 removal requires very low levels of SO_2 and NO_2 entering the CO_2 absorber, as these species also react with the solvent, requiring removal of the degraded solvent and replacement with fresh feed. Thus, high-efficiency SO_2 and NO_X control systems are essential to minimizing solvent consumption costs for post-combustion CO_2 capture; currently the approach to achieving such ultra-low SO_2 concentrations is to add a polishing scrubber, a costly venture. Extensive RD&D is in progress to improve the solvent and system designs for power boiler applications and to develop better solvents with greater absorption capacity, less energy demand for regeneration, and greater ability to accommodate flue gas contaminants.

At present, monoethanolamine (MEA) is the "default" solvent for post-combustion CO_2 capture studies and small-scale field applications. Processes based on improved amines, such as Fluor's Econamine FG Plus and Mitsubishi Heavy Industries' KS–1, await demonstration at power boiler scale and on coal-derived flue gas. The potential for improving amine-based processes appears significant. For example, a recent study based on KS–1 suggests that its impact on net power output for a supercritical PC unit would be 19 percent and its impact on the levelized cost-of-electricity would be 44 percent, whereas earlier studies based on suboptimal MEA applications yielded output penalties approaching 30 percent and cost-of-electricity penalties of up to 65 percent.

Accordingly, amine-based engineered solvents are the subject of numerous ongoing efforts to improve performance in power boiler post-combustion capture applications. Along with modifications to the chemical properties of the sorbents, these efforts are addressing the physical structure of the absorber and regenerator equipment, examining membrane contactors and other modifications to improve gas-liquid contact and/or heat transfer, and optimizing thermal integration with steam turbine and balance-of-plant systems. Although the challenge is daunting, the payoff is potentially massive, as these solutions may be applicable not only to new plants, but to retrofits where sufficient plot space is available at the back end of the plant.

Finally, as discussed earlier, deploying USC PC technology to increase efficiency and lower uncontrolled CO_2 per MWh can further reduce the cost impact of post-combustion CO_2 capture.

Ammonia-Based Processes. Post-combustion CO_2 capture using ammonia-based solvents offers the promise of significantly lower solvent regeneration requirements relative to MEA. In the "chilled ammonia" process owned by ALSTOM and currently under development and testing by ALSTOM and EPRI, respectively, CO_2 is absorbed in a solution of ammonium carbonate, at low temperature and atmospheric pressure.

Compared with amines, ammonium carbonate has over twice the CO_2 absorption capacity and requires less than half the heat to regenerate. Further, regeneration can be performed under higher pressure than amines, so the released CO_2 is already partially pressurized. Therefore, less energy is subsequently required for compression to a supercritical state for transportation to an injection location. Developers have estimated that the parasitic power loss from a full-scale supercritical PC plant using chilled ammonia CO_2 capture could be as low as 15 percent, with an associated cost-of-electricity penalty of just 25 percent. Part of the reduction in power loss comes from the use of low quality heat to regenerate ammonia and reduce the quantity of steam required for regeneration. Following successful experiments at 0.25 MW_e scale, ALSTOM and a consortium of EPRI members built a 1.7 MW_e pilot unit to test the chilled ammonia process on a flue gas slipstream at We Energies' Pleasant Prairie Power Plant. Testing at this site began in late March 2008 and will continue for about 1 year. The American Electric Power Co. (AEP) has announced plans to test a scaled-up design (100,000 tons CO_2/yr, equivalent to about 20 MW_e), incorporating the lessons learned on the 1.7 MW_e unit, at its Mountaineer station in West Virginia, with start-up scheduled for late 2009. AEP intends to capture, inject, and monitor for two-to-five years and, thereafter, continue monitoring CO_2 location in the underground reservoir for another several years. EPRI plans to develop a consortium to support this Mountaineer CO_2 Capture testing.

Other "multi-pollutant" control system developers are also exploring ammonia-based processes for CO_2 removal. For example, Powerspan and NRG Energy, Inc. announced plans in November 2007 to demonstrate a 125 MW_e design of Powerspan's ECO_2 system at the Parish station in Texas starting up in 2012, and last month Basin Electric announced its selection of Powerspan to provide a similar size ECO_2 system for its Antelope Valley station in North Dakota, also with a 2012 start-up goal.

Other Processes. EPRI has identified over 40 potential CO_2 separation processes that are being developed by various firms or institutes. They include absorption systems (typically solvent-based similar to the amine and ammonia processes discussed above), adsorbed (attachment of the CO_2 to a solid that is then regenerated and reused), membranes, and biological systems. Funding comes from a variety of sources, primarily DOE or internal funds, but the funding is neither sufficient or well-enough coordinated to advance the most promising technologies at the speed needed to achieve the goals of high CO_2 capture at societally-acceptable cost and energy drain. EPRI is working with the Southern Co. to select and demonstrate one of these processes at the 20+ MW_e scale, with the collected CO_2 injected into a local underground saline reservoir. The capture portion of this project will be funded mostly by Southern Co., its process supplier, and a collaborative of electricity generation companies assembled by EPRI. The storage portion will be funded largely by DOE under Phase 3 of its Regional Carbon Sequestration Partnership, with co-funding from the private sector. Start-up of the capture unit and compression/transport/injection system is projected for late 2010. Southern Co. and its teammates intend to capture, inject, and monitor for about 4 years and, thereafter, continue monitoring CO_2 location in the underground reservoir for another several years.

Oxy-Fuel Combustion Boilers

Fuel combustion in a blend of oxygen and recycled flue gas rather than in air (known as oxy-fuel combustion, oxy-coal combustion, or oxy-combustion) is gaining interest as a viable CO_2 capture alternative for PC and CFB plants. The process is applicable to virtually all fossil-fueled boiler types and is a candidate for retrofits as well as new power plants.

Firing coal with high-purity oxygen alone would result in too high of a flame temperature, which would increase slagging, fouling, and corrosion problems, so the oxygen is diluted by mixing it with a slipstream of recycled flue gas. As a result, the flue gas downstream of the recycle slipstream take-off consists primarily of CO_2 and water vapor (although it also contains small amounts of nitrogen, oxygen, and criteria pollutants). After the water is condensed, the CO_2-rich gas is compressed and purified to remove contaminants and prepare the CO_2 for transportation and storage.

Oxy-combustion boilers have been studied in laboratory-scale and small pilot units of up to 3 MWt. Two larger pilot units, at ~10 MW_e, are now under construction by Babcock & Wilcox (B&W) and Vattenfall. An Australian-Japanese project team is pursuing a 30 MW_e repowering project in Australia. These larger tests will allow verification of mathematical models and provide engineering data useful for designing pre-commercial systems.

CO_2 Transport and Geologic Storage

Application of CO_2 capture technologies implies that there will be secure and economical forms of long-term storage that can assure CO_2 will be kept out of the atmosphere. Natural underground CO_2 reservoirs in Colorado, Utah, and other western states testify to the effectiveness of long-term geologic CO_2 storage. CO_2 is also found in natural gas reservoirs, where it has resided for millions of years. Thus, evidence suggests that similarly sealed geologic formations will be ideal for storing CO_2 for millennia or longer.

The most developed approach for large-scale CO_2 storage is injection into depleted or partially depleted oil and gas reservoirs and similar geologically sealed "saline formations" (porous rocks filled with brine that is impractical for desalination). Partially depleted oil reservoirs provide the potential added benefit of enhanced oil recovery (EOR). [EOR is used in mature fields to recover additional oil after standard extraction methods have been used. When CO_2 is injected for EOR, it causes residual oil to swell and become less viscous, allowing some to flow to production wells, thus extending the field's productive life.] By providing a commercial market for CO_2 captured from industrial sources, EOR may help the economics of CCS projects where it is applicable, and in some cases might reduce regulatory and liability uncertainties. Although less developed than EOR, researchers are exploring the effectiveness of CO_2 injection for enhancing production from depleted natural gas fields (particularly in compartmentalized formations where pressure has dropped) and from deep methane-bearing coal seams. DOE and the International Energy Agency are among the sponsors of such efforts. However, at the scale that CCS needs to be deployed to help achieve atmospheric CO_2 stabilization at an acceptable level, EPRI believes that the primary economic driver for CCS will be the value of carbon that results from a future climate policy.

Geologic sequestration as a CCS strategy is currently being demonstrated in several RD&D projects around the world. The three largest projects (which are non-power)—Statoil's Sleipner Saline Aquifer CO_2 Storage project in the North Sea off of Norway; the Weyburn Project in Saskatchewan, Canada; and the In Salah Project in Algeria—each sequester about 1 million metric tons of CO_2 per year, which matches the output of one baseloaded 150–200 MW coal-fired power plant. With 17 collective operating years of experience, these projects have thus far demonstrated that CO_2 storage in deep geologic formations can be carried out safely and reliably. Statoil estimates that Norwegian greenhouse gas emissions would have risen incrementally by 3 percent if the CO_2 from the Sleipner project had been vented rather than sequestered.[4]

Table 2 lists a selection of current and planned CO_2 storage projects as of early 2007. Update to Table 2: The DF–1 Miller project has been put on hold and may be cancelled, so no CO_2 capture is expected by 2010. The DF-Carson project may not startup by 2011 as planned. DOE has indicated that it plans to revise the FutureGen project so CO_2 storage will not take place until after 2012. In October 2007, the DOE awarded the first three large scale carbon sequestration projects in the United States. The Plains Carbon Dioxide Reduction Partnership, Southeast Re-

[4] *http://www.co2captureandstorage.info/project__specific.php?project__id=26.*

gional Carbon Sequestration Partnership, and Southwest Regional Partnership for Carbon Sequestration, will conduct large volume tests for the storage of one million or more tons of CO_2 in deep saline reservoirs in the U.S.

Table 2.—Select Existing and Planned CO_2 Storage Projects as of Early 2007

Project	CO_2 Source	Country	Start	Anticipated amount injected by:		
				2006	2010	2015
Sleipner	Gas. Proc.	Norway	1996	9 MT	13 MT	18 MT
Weyburn	Coal	Canada	2000	5 MT	12 MT	17 MT
In Salah	Gas. Proc.	Algeria	2004	2 MT	7 MT	12 MT
Snohvit	Gas. Proc.	Norway	2007	0	2 MT	5 MT
Gorgon	Gas. Proc.	Australia	2010	0	0	12 MT
DF–1 Miller	Gas	U.K.	2009	0	1 MT	8 MT
DF–2 Carson	Pet Coke	U.S.	2011	0	0	16 MT
Draugen	Gas	Norway	2012	0	0	7 MT
FutureGen	Coal	U.S.	2012	0	0	2 MT
Monash	Coal	Australia	N/A	0	0	N/A
SaskPower	Coal	Canada	N/A	0	0	N/A
Ketzin/CO_2 STORE	N/A	Germany	2007	0	50 KT	50 KT
Otway	Natural	Australia	2007	0	100 KT	100 KT
Totals				16 MT	35 MT	99 MT

Source: Sally M. Benson (Stanford University GCEP), "Can CO_2 Capture and Storage in Deep Geological Formations Make Coal-Fired Electricity Generation Climate Friendly?" Presentation at Emerging Energy Technologies Summit, UC Santa Barbara, California, February 9, 2007. [Note: Statoil has subsequently suspended plans for the Draugen project and announced a study of CO_2 capture at a gas-fired power plant at Tjeldbergodden. BP and Rio Tinto have announced the coal-based "DF–3" project in Australia.]

Enhanced Oil Recovery. Experience relevant to CCS comes from the oil industry, where CO_2 injection technology and modeling of its subsurface behavior have a proven record of accomplishment. EOR has been conducted successfully for 35 years in the Permian Basin fields of west Texas and Oklahoma. Regulatory oversight and community acceptance of injection operations for EOR seem well established.

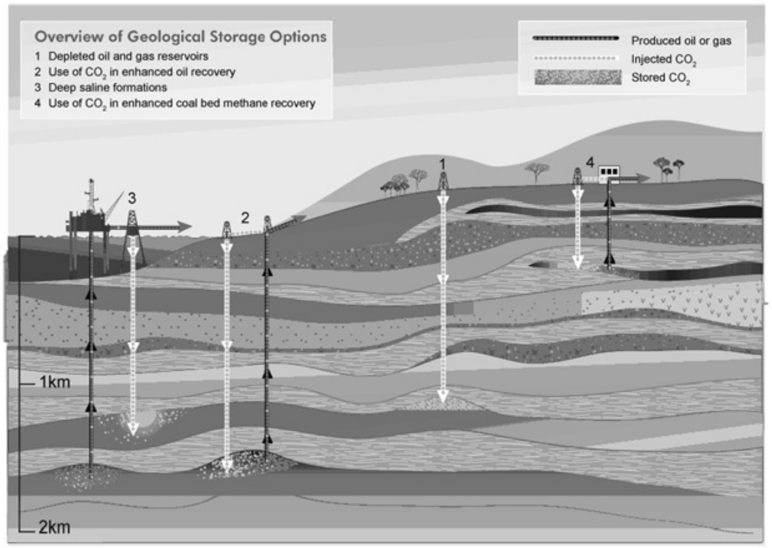
Although the purpose of EOR heretofore has not been to sequester CO_2, the practice can be adapted to include large-volume residual CO_2 storage. This approach is being demonstrated in the Weyburn-Midale CO_2 monitoring projects in Saskatchewan, Canada. The Weyburn project uses captured and dried CO_2 from the Dakota Gasification Company's Great Plains synfuels plant near Beulah, North Dakota. The CO_2 is transported via a 200-mile pipeline constructed of standard carbon steel. Over the life of the project, the net CO_2 storage is estimated at 20 million metric tons, while an additional 130 million barrels of oil will be produced.

Although EOR might help the economics of early CCS projects in oil-patch areas, EOR sites are ultimately too few and too geographically isolated to accommodate much of the CO_2 from widespread industrial CO_2 capture operations. In contrast, saline formations are available in many—but not all—U.S. locations.

CCS in the United States

A DOE-sponsored R&D program, the "Regional Carbon Sequestration Partnerships," is engaged in mapping U.S. geologic formations suitable for CO_2 storage. Evaluations by these Regional Partnerships and others suggest that enough geologic storage capacity exists in the U.S. to hold many centuries' production of CO_2 from coal-based power plants and other large point sources.

The Regional Partnerships are also conducting pilot-scale CO_2 injection validation tests across the country in differing geologic formations, including saline formations, deep unmineable coal seams, and older oil and gas reservoirs. Figure 11 illustrates some of these options. These tests, as well as most commercial applications for long-term storage, will use CO_2 compressed for volumetric efficiency to a liquid-like "supercritical" state; thus, virtually all CO_2 storage will take place in formations at least a half-mile deep, where the risk of leakage to shallower groundwater aquifers or to the surface is usually very low.



Source: Peter Cook, CO_2CRC, in Intergovernmental Panel on Climate Change, Special Report "Carbon Dioxide Capture and Storage," http://www.ipcc.ch/pub/reports.htm

Figure 11 – Illustration of potential geological CO_2 storage site types

After successful completion of pilot-scale CO_2 storage validation tests, the Partnerships will undertake large-volume storage tests, injecting quantities of ~1 million metric tons of CO_2 or more over a several year period, along with post-injection monitoring to track the absorption of the CO_2 in the target formation(s) and to check for potential leakage.

The EPRI–CURC Roadmap identifies the need for several large-scale integrated demonstrations of CO_2 capture and storage. This assessment was echoed by MIT in its recent *Future of Coal* report, which calls for three to five U.S. demonstrations of about 1 million metric tons of CO_2 per year and about 10 worldwide.[5] These demonstrations could be the critical path item in commercialization of CCS technology. In addition, EPRI has identified 10 key topics[6] where further technical and/or policy development is needed before CCS can become fully commercial:

- Caprock integrity
- Injectivity and storage capacity
- CO_2 trapping mechanisms
- CO_2 leakage and permanence
- CO_2 and mineral interactions
- Reliable, low-cost monitoring systems
- Quick response and mitigation and remediation procedures
- Protection of potable water
- Mineral rights
- Long-term liability

Figure 12 shows that EPRI's recommended large-scale integrated CO_2 capture and storage demonstrations is temporally consistent with the Regional Partnerships' "Phase III" large-volume CO_2 storage test program. EPRI believes that many of the storage demonstrations should use CO_2 that comes from coal-fired boilers to address any uncertainties that may exist about the impact of coal-derived CO_2 on its behavior in underground formations.

[5] *http://web.mit.edu/coal/The Future of Coal.pdf.*
[6] EPRI, *Overview of Geological Storage of CO_2*, Report ID 1012798.

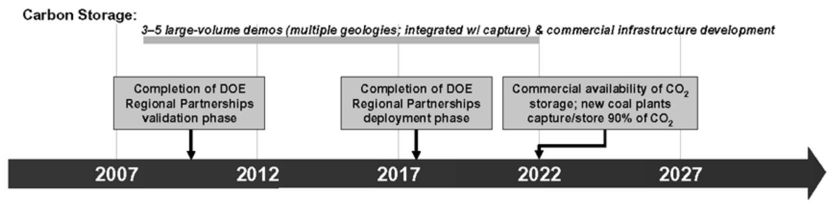


Figure 12 – Timing of CO_2 storage technology RD&D activities and milestones

CO_2 Transportation

Mapping of the distribution of potentially suitable CO_2 storage formations across the country, as part of the research by the Regional Partnerships, shows that some areas have ample storage capacity while others appear to have little or none. Thus, implementing CO_2 capture at some power plants may require pipeline transportation for several hundred miles to suitable injection locations, possibly in other states. Although this adds cost, it should not represent a technical hurdle because long-distance, interstate CO_2 pipelines have been used commercially in oilfield EOR applications. Economic considerations dictate that the purity requirements of coal-derived CO_2 be established so that the least-cost pipeline and compressor materials can be used at each application. From an infrastructure perspective, EPRI expects that early commercial CCS projects will take place at coal-based power plants near sequestration sites or an existing CO_2 pipeline. As the number of projects increases, regional CO_2 pipeline networks connecting multiple industrial sources and storage sites will be needed.

Policy-Related Long-Term CO_2 Storage Issues

Beyond developing the technological aspects of CCS, public policy needs to address issues such as CO_2 storage site permitting, long-term monitoring requirements, and post-closure liability. CCS represents an emerging industry, and the jurisdictional roles among Federal and state agencies for regulations and their relationship to private carbon credit markets operating under Federal oversight has yet to be determined.

Currently, efforts are under way in some states to establish regulatory frameworks for long-term geologic CO_2 storage. Additionally, stakeholder organizations such as the Interstate Oil and Gas Compact Commission (IOGCC) are developing their own suggested regulatory recommendations for states drafting legislation and regulatory procedures for CO_2 injection and storage operations.[7] Other stakeholders, such as environmental groups, are also offering policy recommendations. EPRI expects this field to become very active soon.

A state-by-state approach to sequestration may not be adequate because some geologic formations, which are ideal for storing CO_2, underlie multiple states. At the Federal level, the U.S. EPA published a first-of-its-kind guidance (UICPG #83) on March 1, 2007, for permitting underground injection of CO_2.[8] This guidance offers flexibility for pilot projects evaluating the practice of CCS, while leaving unresolved the requirements that could apply to future large-scale CCS projects.

Long-Term CO_2 Storage Liability Issues

Long-term liability for injected CO_2 will need to be assigned before CCS can become fully commercial. Because CCS activities will be undertaken to serve the public good, as determined by government policy, and will be implemented in response to anticipated or actual government-imposed limits on CO_2 emissions, a number of policy analysts have suggested that the entities performing these activities should be granted a measure of long-term risk reduction assuming adherence to proper procedures during the storage site injection operations and closure phases.

RD&D Investment for Advanced Coal and CCS Technologies

Developing the suite of technologies needed to achieve competitive advanced coal and CCS technologies will require a sustained major investment in RD&D. As shown in Table 3, EPRI estimates that an expenditure of approximately $8 billion will be required in the 10-year period from 2008–2017. The MIT *Future of Coal* report estimates the funding need at up to $800–$850 million per year, which ap-

[7] *http://www.iogcc.state.ok.us/PDFS/CarbonCaptureandStorageReportandSummary.pdf.*
[8] *http://www.epa.gov/safewater/uic/pdfs/guide*__uic__*carbonsequestration*__*final-03-07.pdf.*

proaches the EPRI value. Further, EPRI expects that an RD&D investment of roughly $17 billion will be required over the next 25 years.

Investment in earlier years may be weighted toward IGCC, as this technology is less developed and will require more RD&D investment to reach the desired level of commercial viability. As interim progress and future needs cannot be adequately forecast at this time, the years after 2023 do not distinguish between IGCC and PC.

Table 3.—RD&D Funding Needs for Advanced Coal Power Generation Technologies with CO_2 Capture

<table>
<tr><th></th><th>2008–12</th><th>2013–17</th><th>2018–22</th><th>2023–27</th><th>2028–32</th></tr>
<tr><td>Total Estimated RD&D Funding Needs (Public + Private Sectors)</td><td>$830M/yr</td><td>$800M/yr</td><td>$800M/yr</td><td>$620M/yr</td><td>$400M/yr</td></tr>
<tr><td>Advanced Combustion, CO_2 Capture</td><td>25%</td><td>25%</td><td>40%</td><td rowspan="2">80%</td><td rowspan="2">80%</td></tr>
<tr><td>Integrated Gasification Combined Cycle (IGCC), CO_4 Capture</td><td>50%</td><td>50%</td><td>40%</td></tr>
<tr><td>CO_2 Storage</td><td>25%</td><td>25%</td><td>20%</td><td>20%</td><td>20%</td></tr>
</table>

By any measure, these estimated RD&D investments are substantial. EPRI and the members of the *CoalFleet for Tomorrow®* program, by promoting collaborative ventures among industry stakeholders and governments, believe that the costs of developing critical-path technologies for advanced coal and CCS can be shouldered by multiple participants. EPRI believes that government policy and incentives will also play a key role in fostering CCS technologies through early RD&D stages to achieve widespread, economically feasible deployment capable of achieving major reductions in U.S. CO_2 emissions.

Senator KERRY. Thanks, Mr. Novak.

I want to welcome Senator Stevens here. As I mentioned, Senator Stevens and I have joined together to introduce a commercial-scale, both capture and sequestration effort here, which, I personally think in light of the testimony we've heard would be very important to have funded as rapidly as possible.

Let me just ask this threshold question. Is there anybody at the table who has testified who does not accept the IPCC reports and the fundamental science of anthropogenic contribution to climate change?

So, every one of you accept that science. Is there anybody who differs with the urgency expressed in the most recent reports about the levels of greenhouse gases that we can emit before we reach a tipping point, *i.e.,* two degrees, 450 parts per million? OK.

Yes, Doctor?

Dr. MARBURGER. Yes, I wouldn't accept that at face value, I think the concept of a tipping point is controversial.

Senator KERRY. Do you believe there is a greenhouse gas standard which you believe raises alarm bells? Do you think we can go the 609 parts per million that we are heading to at the current rate?

Dr. MARBURGER. In my mind, the current emission rates raise alarm bells.

Senator KERRY. The current rates do? So, in other words, you're arguing from the point of view that it is possible that that may be generous? That the 450 may be generous, that it may be less than that before you reach tipping point?

Dr. MARBURGER. It's not clear to me whether there is a tipping point. It is clear that there is a anthropogenic impact on the climate, that if let go without action, will cause unacceptable impacts——

Senator KERRY. Fair enough, let's work with that, at least.

If you accept, as everybody has indicated, the fundamentals, here, then what Mr. Hawkins has suggested, which I have, actually put into legislation. We should not build one pulverized coal-fired power plant that does not now move toward some variant of what has been talked about here, the IGCC, gasification, etc., because otherwise, we are digging the hole deeper, are we not?

Dr. Marburger?

Dr. MARBURGER. It would be highly desirable to make sure that new coal-fired power plants have the capacity for retrofitting with carbon capture and storage as that technology becomes widespread.

Senator KERRY. Are we, in fact, building power plants that are retrofittable in all circumstances today?

Anybody? Mr. Hawkins?

It's my understanding that we're building some pulverized coal-powered power plants that are just the old technology. They are not necessarily set up for retrofit?

Mr. HAWKINS. Yes, I participated as an advisor to the MIT Coal Study that was released last year, and one of the things that they pointed out correctly, is that while a gasification plant that is built without capture is cheaper to retrofit than a pulverized coal plant, retrofitting either of them is a pretty expensive proposition. It is much better to build the plant with that capture equipment from the start and there is no reason to avoid doing that. We have the technology to do it. The challenges are a matter of economics and we have policies that can overcome the economic hurdles. We should get on with it.

Senator KERRY. Mr. Novak, you're nodding your head.

Mr. NOVAK. It looks, in our opinion, you can retrofit some of these plants, it depends on——

Senator KERRY. When you say our opinion, just for the record, say it again.

Mr. NOVAK. The Electric Power Research Institute. You can retrofit plants that are being built today, it's a question of space, the ability to fit those plants, and can you get that CO_2 that you capture to a storage site? That's another question you'd have to—to pipe it. There's no question, it will cost money to do that, and especially a pulverized coal plant, you're talking about a 30 percent reduction, a 30 percent energy penalty, that much less electricity.

Senator KERRY. Well, I agree that this question of cost on the piping is a big question, and in some parts of the country it's going to be far more economical and feasible than in other parts of the country.

Is there a distinction here as to whether or not you ought to allow a power plant, if they can't pipe economically, or do you make some provision for that piping? What's the approach here?

Mr. NOVAK. I think that—looking at what the European Union is doing, they're—they have a directive that is asking all new coal plants to be—to be "capture ready," to have the space, to have the ability to fit, and to do an assessment of the ability to transport and store that CO_2 to some location. So that's—that's one option that one could consider for new plants.

Senator KERRY. Now Dr. Strakey, I'd like to try to pin down where we are in terms of the FutureGen project. Obviously the initial flurry was that this was being abandoned. I mean, that was the announcement, we're abandoning the FutureGen project as we know it. And now we talk about it as a restructuring. I'm a little confused, and obviously Mr. Mudd is concerned at the moment about a 5-year delay and other potential here.

So, can you clarify for the Committee, where do we stand, specifically with respect to the Department's efforts in the FutureGen sector and what is the status of FutureGen today?

Dr. STRAKEY. OK, as you know, the Department was very concerned about the cost growth in FutureGen project, and we thought that going forward with the FutureGen project as it was originally proposed, presented unacceptable financial risk in terms of cost escalation.

And as a result, we started—going back to late last fall—looking at other alternatives to try to accomplish the same thing in a reasonable time-frame.

And the situation, since FutureGen started has changed. Right now, we have a number of plants that are anticipated being built, but they're faced with a dilemma. Can they build it with carbon capture? They don't know. And I think they would be willing to build coal plants equipped with carbon capture if the government helps finance that part of the project.

In addition, one of the reasons that they can't build them is because they're facing permit obstacles, and we've seen that in a number of states projects have been cancelled or moved, as a result of these permit issues. If they have carbon capture equipment available there, they might be able to get past their permit issues and get these plants built.

Senator KERRY. It seems like there's a contradiction in that. If they have it, they can then be built. The whole idea was that you were going to help them have it. And in your testimony, your written testimony, you say gasification technology holds substantial promise as the best coal conversion technology option to utilize carbon capture technologies.

So, if that's the case, why has the Federal Government reduced its commitment, or abandoned its commitment to IGCC with CCS by dropping the FutureGen project? Isn't that the best way to get everybody permitted and up and most rapidly bring this to conclusion?

Dr. STRAKEY. We believe that by changing to the revised FutureGen or FutureGen restructured—we also called it plan B—then we'll be able to have multiple demonstrations, and they will come online about 2 years later. But they will finish in about the same time-frame, maybe a little bit later, but that will lead to the next wave of commercial plants in a quicker manner.

Senator KERRY. So, Mr. Mudd, what's your reaction to that? Why do you believe there's a 5-year delay? Obviously you disagree, and what's the downside?

Mr. MUDD. Mr. Chairman, it takes a long time for the U.S. Government, appropriately so, to come up with a Request for Proposals, to receive the bids, to negotiate the contract, and then to award the contract, and then to do the design and cost estimate for it. And then there's also a program rule that says you can not begin procurement or the detailed design until you have met all the NEPA requirements, gotten the environmental impact statement.

Typically, it takes 2 to 3 years at best to get the EIS. Now we're very fortunate because of the phenomenal amount of work that was done in advance, to the get the environmental impact statement—as a credit to the hard working employees of the Department of Energy—to get that done in approximately 14 to 16 months.

Now having said that, if we look at—right now you start with the new program today, and then what is the earliest—and one can ask the questions and conjecture—when's the earliest that the bids would come in to the Department of Energy, what's the earliest that the DOE could award the contracts, and then do the preliminary design, and then do the EIS, and then, at that point, be able to procure the equipment in the face of increasing escalation to these prices, with the expectation that the cost will go down? I think these are some severe challenges that one would look at, and I believe that it would be 5 years, basically, before the DOE, before a participant would be in the position to even begin to procure the equipment, based on that.

Senator KERRY. Dr. Strakey?

Dr. STRAKEY. I would say that we are very close to having a solicitation ready to go out on the street.

Senator KERRY. Well, how about how long does it take once you've done that?

Dr. STRAKEY. Mr. Mudd said that that it would take 3 years to do the NEPA process, and I think we—in working through FutureGen—we cut that time in half. So, I think that our estimates are a little more optimistic about when the plants would come online than Mr. Mudd's.

Senator KERRY. Mr. Childress or Mr. Hawkins, anybody?

Dr. STRAKEY. But it will be after the original date.

Senator KERRY. Mr. Hawkins?

Mr. HAWKINS. This cancellation or restructuring is clearly going to result in a delay. I think the proof is in the pudding. It took 5 years to get from the announcement——

Senator KERRY. Do you agree there will be a delay, Dr. Strakey?

Dr. STRAKEY. Yes.

Senator KERRY. Why is that acceptable?

Dr. STRAKEY. Because we think by having a multiple demonstrations, it will convince the commercial sector to move more rapidly, and that they'll be prepared to take that next step for a number of commercial plants faster.

Senator KERRY. Mr. Hawkins?

Mr. HAWKINS. Again, if we enacted bills that are getting serious consideration in Congress, we'll have multiple demonstrations, and we do not need to wait for a new set of authorizations, a new set of appropriations, a new Administration.

The truth is that this restructuring is handing it off to the next Administration. This Administration is not going to do anything, rather than, maybe get a solicitation out the door, possibly get some responses to that solicitation at the time they're leaving office.

This doesn't make any sense. We need a faster acting relief package.

Senator KERRY. Well, we'll come back to it.

Senator Ensign?

Senator ENSIGN. Thank you, Mr. Chairman.

Obviously there's a difference of opinion depending on where you sit. If we had unlimited funds, we would fund the FutureGen plant and fund the other ones that would be proving other technology at the same time, moving on a dual-track process, so that we could have other commercial technologies come onboard.

But I do want to ask you this question. Because of the different types of coal that we have in the United States, if you had just the one FutureGen plant, wouldn't that leave out half of the United States, Mr. Mudd?

Mr. MUDD. Senator Ensign, the FutureGen project is being designed to be able to address more than the eastern bituminous coal. We do recognize that there are efficiency and cost penalties associated with the other coals, and it's an issue that absolutely must be solved. And the way the FutureGen has been designed is to be able to address those penalties associated with the different types of coals and be able to test the different types of coals.

With respect to the carbon sequestration itself, while there are different geologic formations, there are important common parts, including the liability, the permitting, the mineral rights, and so on. The Alliance spent over $1.5 million of both—of the project funds, both private funds and government funds, in addressing the legal issues associated with injecting CO_2. It's not a trivial matter to identify the mineral rights, negotiate them, and be able to prepare to inject in those areas. Those are common regardless of where you built it.

Senator ENSIGN. Correct.

Except, Dr. Strakey, maybe you could address this. The western United States is growing rapidly and our electricity demands are growing rapidly as well. My home State and Arizona are some of the fastest growing states in the United States.

With FutureGen and the significant problems that you have just identified, Mr. Mudd, it would seem to me that if we need power plants in the future, we're going to be much farther behind as far as clean coal, carbon capture, and sequestration technologies in the West than the East would be. Because of that, we coulbe be at a significant disadvantage.

You have mentioned some of the commonalities, but there are significant differences also in storage. Because we are not just looking at how you can store it, but what are the effects of storing it. I believe we must study this over several years. Isn't that correct?

Dr. STRAKEY. Yes, that is correct. And one of the things we're looking at in the Carbon Sequestration Regional Partnerships, is doing some large volume injection tests around the country so we get some idea of the storage capability and what the issues are with different formations.

I would also add that there is an advantage having multiple demonstrations, operating on different coals, including both western and eastern coals, because whichever gasifier you choose, it's really going to be optimized for one particular coal. And although you can test different coals in that gasifier, as was planned in FutureGen originally, it's not the same as having the information on optimized gasifiers for each coal.

Senator ENSIGN. If we were to go with what I mentioned, a dual-track approach, what the Administration has proposed, as well as keeping the FutureGen plant, does anybody know how much that would cost? Are we talking about doubling the cost or are we talking 2½ times or 1½ times? Does anybody have any idea?

Dr. STRAKEY. Well, our estimate for the restructured FutureGen would be in the order of $300 to $600 million per project, of Federal funds. And I think the Federal funds in FutureGen original project is about $1.3 billion remaining.

Senator ENSIGN. How much of that has already been spent? Has most of that already been spent on the FutureGen plant?

Dr. STRAKEY. No, a very small amount——

Senator ENSIGN. OK.

Dr. STRAKEY. We're in the design stage.

Senator ENSIGN. OK.

Dr. STRAKEY. Very small.

Mr. MUDD. To date, the funds have been about $40 million in government money and $10 million in private money on FutureGen.

Senator ENSIGN. OK, so we are talking approximately double if you are doing four or five of these demonstration projects. You are looking at probably doubling the amount of money then, correct?

Dr. STRAKEY. We're thinking, for the same $1.3 billion, we might get two to four additional demonstrations.

Senator ENSIGN. OK.

Thank you, Mr. Chairman. That's all the questions that I have.

Senator KERRY. Thank you very much.

Let me just pin down a few things here and then we can hopefully wrap up.

Mr. Hawkins, what level of capture do we need to achieve from coal-fired power plants?

Mr. HAWKINS. Well, over the long term, we really have to get as much carbon out of the power plants as possible. Right now we think that it's feasible to do 85 to 90 percent. Our view is based on the history of things like SO_2 scrubber technology, that as these systems get deployed, they'll be optimized and will do better and better.

And, our view is that we can expect to have commercially operating capture systems that are in the mid-90s or possible even higher, but we won't start there. We're probably going to start, you know, with something less than that, but the important thing is to get the initial ones deployed, get the operating experience, and then allow the next designs to build on that operating experience.

Senator KERRY. Dr. Strakey, originally you had a 90 percent capture requirement on the Mattoon, correct?

Dr. STRAKEY. That's correct.

Senator KERRY. Will that be transferred down to these other facilities?

Dr. STRAKEY. We're still considering that. In the public comments that we had on the draft Request for Information, there were quite a few comments that we should lower that and perhaps we may lower it.

Senator KERRY. Why would you lower it, given the increased science and the fact that you've already imposed that, previously?

Dr. STRAKEY. I think when you get to around 85 percent or in that neighborhood, for certain gasifiers, especially the ones that produce a little bit of methane, it's very difficult and expensive to get from 85 to 90. So, there's some kind of economic breakpoint around there, but generally——

Senator KERRY. But absent some indication that we can tolerate that additional percentage of emission, don't we have to?

Dr. STRAKEY. I'm sorry?

Senator KERRY. Well, absent some indication that you can get by with 85 percent, don't you have to set the 90 percent and don't you have to meet the standard that science tells you you've got to reduce?

Dr. STRAKEY. Well, I think in the long run, you may even have to go above 90.

Senator KERRY. I agree, which is why I'm wondering why we're going below 90.

Dr. STRAKEY. Because it's an economic—it's better——

Senator KERRY. Economics don't work out in the far run and on the mitigation.

Dr. STRAKEY. I would also add one other important point.

Senator KERRY. Let me just finish that, though. The economics are miserable if you've got to move millions of people and the insurance industry walks away from insuring people, and shorelines change, and you're spawning grounds disappear, and vegetation migrates north, and a whole bunch of other things happen. You want to talk about costs, factor in the cost of not doing this.

Dr. STRAKEY. I understand that.

Senator KERRY. But are you really translating it into the policy?

Dr. STRAKEY. I think you have options, also. If you build a plant that's, say, 85 to 90 percent now, to increase that later, either through just changes to the process itself or more importantly, through introduction of biomass into the coal gasification plant itself. And in situations like that, some of our studies show you can go net-carbon negative. Now that's relatively new, but that may be a very attractive option for converting some of these plants later on to even higher——

Senator KERRY. But will you do that if you don't set the standard? It's like kids with their homework, if you don't tell them when it's due, it doesn't get done.

Dr. STRAKEY. I'm not sure about that one, but we think that, you know, 85 percent is a heck of a lot better than what you have now and what a lot of people are considering.

And by the way, the back-up, the default option here is, if we do nothing, we'll be burning natural gas and that has carbon in it. And at some point, we're going to have to take that out. So if we shift the economy to heavier reliance on natural gas, we'll pay the price for that later. And it may be even worse.

Senator KERRY. I'm not for that. I don't disagree with you. But as someone pointed out earlier, we don't have the reserves and the demand is not going to allow that to happen anyway. You look at the demand curve in China today, let alone other countries. I mean, that's a nonstarter.

Dr. STRAKEY. I agree.

Senator KERRY. Well——

Dr. STRAKEY. By the way, we have not actually made a determination of what the level would be, whether it would be 80, 90, whatever.

Senator KERRY. Well, I urge you, given the givens here, to really take a hard look at the facts as they've been laid out and as the scientists have laid them out and what the demand is. I think it would be a huge mistake to move backward on that standard, given the unbelievable amount of science that is now accruing. Most recently the Arctic, Antarctic ice break-off and what we're seeing. Every bit of feedback there is, is coming back faster and greater than was predicted. Cautious people, it seems to me, would take that evidence and process it appropriately.

Mr. CHILDRESS. Senator, if I might add one item here. We're getting very, and importantly so, focused on FutureGen as a Federal program. I can say this categorically, I know of no publicly announced IGCC in the United States that's prepared to move forward with CCS, the economics are not there. And in the absence of a program—I don't want the headlines to say "Jim Childress agrees with Dave Hawkins on everything," but in the absence of a program that provides regulatory certainty, and addresses liability issues, Mr. Hawkin's cost sharing scheme may or may not work for anybody. But you've got to have some way to cost share so that those projects that are going to cost more, we know that, can move forward financially, can get the investors necessary to do it.

In the absence of this, what we're seeing is a cluster of gasification projects on the Gulf Coast. It's the industrial gasification I talked about. And, it's for chemicals, for fertilizers, even TXU, former TXU, now Illuminate, is looking at, has not announced publicly, some potential IGCCs, but they have a carbon sink, which is enhanced oil recovery, where you make money. Instead of spending money to put it in the ground, you're going to make money.

Just a couple of days ago a project was announced in Louisiana, producing substitute natural gas. Denberry Resources has committed to buy that CO_2 for enhanced oil recovery, and they floated a big GO Zone Bond, $1.1 billion bond. That is a package that makes sense, but it comes together because somebody will pay you for the CO_2 and it's not an added cost to capture it and put it in the ground.

Senator KERRY. Mr. Novak, there are a limited number of IGCC plants with CCS I know, how many do you know of?

Mr. NOVAK. IGCC with CCS? None.

Senator KERRY. None at all.

Mr. NOVAK. There are lots of gasification, industrial gasification plants that capture——

Senator KERRY. The North Dakota one doesn't include both IGCC and CCS?

Mr. NOVAK. That's a gas—industrial gasification facility that captures CO_2 and produces—and pipes that CO_2 to Canada.

Senator KERRY. It produces it for use in enhanced oil recovery?

Mr. NOVAK. That's correct.

Senator KERRY. It's not, OK.

Mr. NOVAK. It produces gas, it's a gas——

Senator KERRY. Right, so it has capture of it, no storage.

Mr. NOVAK. It has capture, but no power generation.

Senator KERRY. Right. Oh, OK. I see, and the combined cycle component of it.

Mr. NOVAK. Right. And it ships it to Canada and then Canada pays it for the CO_2. That's——

Senator KERRY. Right.

Mr. NOVAK.—that's the economic difference.

Senator KERRY. How many different locations are we using it for, the EOR?

Mr. HAWKINS. There are about 70 projects, most of them in the United States, a few outside the United States, but we have a couple of——

Senator KERRY. We've been doing that for a long time, haven't we?

Mr. HAWKINS. Yes, since the 1970s, and we're currently injecting something on the order of 35 million tons of CO_2 a year into these formations. Unfortunately, about 80 percent of that is pulled out of other natural CO_2 reservoirs, so we're not actually getting——

Senator KERRY. Right, I realize that.

Mr. HAWKINS.—abatement.

Senator KERRY. I know we're taking it from natural CO_2, I realize that.

Mr. HAWKINS. But we do have lots of experience with massive amounts of geologic CO_2 injection, not quite as large as will come out of a typical power plant, but large enough to demonstrate that we know how to handle these high pressure gases in very large quantities, and do it safely.

Mr. NOVAK. But I would suggest that we do need to do some tests in geologic formations, in these deep aquifers or saline formations to show that we know what happens to that CO_2 when we——

Senator KERRY. Oh, sure we do. I couldn't agree more and I testified recently, before the Energy Committee, because I have a regulatory protocol that we've put together that we need to get in place.

People have got to know what the standards are going to be, what's the liability going to be, what are the rules going to be, how does this work? We've got to get that out there. I think that's urgent. As urgent as anything else to encouraging people to know the rules they're playing by, which is important when you're dealing with money. People are going to have to have a sense of that.

Mr. HAWKINS. It is important to note that in addition to the enhanced oil recovery activities, we have a couple of fairly long-running projects that are injecting CO_2 into these other types of formations. One under the North Sea that began in 1996, it's under the seabed in a—in a saline aquifer formation. And another one in Algeria that is associated with a gas field, but it's not used for enhanced oil recovery, it's permanent storage.

Senator KERRY. Mr. Novak, do you have any sense of the level and sort of structure that the the electro-power industry, might put into the deployment of CCS technology?

Mr. NOVAK. Senator, we've done an analysis that looks at, if we had to meet a future climate constraint, and we put one into a model, and we put in cost and performance data for the alternatives, for energy efficiency, renewable, coal with capture and storage, nuclear power, natural gas, and a large portion of that future generation would come from CO_2, coal with CO_2 capture and storage, and nuclear. Those are the two largest ones, based on straight economics.

Senator KERRY. What about if a cap and trade were to pass here, and we were to put that into effect. Would that speed up the application of IGCC technology with CCS?

Mr. NOVAK. Senator, it would clearly move up—it could impact deployment because then there's a price of carbon. You don't—you wouldn't capture and store carbon unless there's a reason to do so. There's no economic reason to capture and store CO_2. You either need a cap that puts a price on carbon, a carbon tax that puts a price on carbon, a mandate, or a tax credit, for example, that would make it economic for you to capture and store CO_2.

I think the big issue in timing, Senator, is proving storage. It takes three to 5 years to build a facility, three to 5 years to inject, three to 5 years to monitor. We've got to get those tests underway and done. Unless we use CO_2—we can use CO_2 from existing sources and maybe move that storage test up and the regional partnerships are doing that. But we need to get these large-scale demonstrations.

We also need to build IGCC with capture and storage to show we can capture it and we can burn hydrogen at full scale in a combined-cycle turbine and reliably generate electricity. We need to do pulverized coal.

Senator KERRY. How widespread is the storage? I mean, the storage concept? Conceptually we know it works already, don't we? As we just said, we're taking natural storage centers and using them, so it's been stored. And if we're taking it out of there, I assume we can put it in there.

Mr. MUDD. Senator Kerry, though, I want to underscore that you can look at any of the components of a plan—of carbon capture and sequestration, and the gasification, and IGCC, and see how bits and pieces have been proven throughout the world. What has not been done is the total integration of all of these complex systems.

Senator KERRY. I completely agree and I understand, which is why I introduced the legislation to get a commercial-scale project out there.

Here's the way I see it. There are certain saline aquifers, other areas where we don't know how air tight it is, we don't know whether it's going to leak, et cetera. There are some places where you've obviously got to test it. But in theory and in principal, we know that there are existing caverns or cisterns where, for years, something was contained in there, in a non-releasable form, until we drilled in and opened it up.

Mr. NOVAK. I think the work that's done under the Department of Energy Regional Partnerships work has done an atlas of geologic storage formation. They look like they—they appear to be widespread throughout the U.S., not in every State, but a lot of potential capacity. The phrase, "We are the Saudi Arabia of coal, we are the Saudi Arabia of storage capacity in the world." We have enough, I think, as one of the other witnesses testified, but we need to do some site-specific tests for those geologic formations, in those regions to make sure that it's sound and it's suitable——

Senator KERRY. Right, I understand.

Mr. NOVAK.—and do the tests.

Senator KERRY. I understand that.

When you talked about a zero emission or a net negative emission, is that only achievable factoring in the storage? Could you do that without storage?

Dr. STRAKEY. No, storage is an essential part of that.

Senator KERRY. It's critical. There's no other theory about how you take the CO_2 and dispose——

Dr. STRAKEY. That's right. Essentially, with this extra increment, you're capturing CO_2 from the atmosphere and storing it geologically through——

Senator KERRY. So what's the best estimate, from a policy point of view, as to how much CO_2, and for how long can we do that? I mean, there are limits ultimately to how much you're going to be able to capture. Is this geared to the ultimate weaning of fossil fuels altogether? Or is it geared as some earlier date, in effect, because of the limits on storage itself? How long do we get the economic benefit of this, and does that amortize out adequately?

Mr. CHILDRESS. The DOE puts a range of 200 to 500 years given current generating capacity in the U.S. And importantly, most of that, 90 plus percent of that, is saline aquifers. Enhanced oil recovery is the low-hanging fruit today, that's why everybody's being attracted to that. But the silver bullet is saline aquifers, which is why, personal opinion, we certainly need one or more IGCCs with CCS injecting into saline aquifers.

Dr. STRAKEY. Senator Kerry?

Senator KERRY. Yes, sir.

Dr. STRAKEY. If I could add to that. Our estimate for storage in saline aquifers, the upper estimate was on the order of 500 years. For enhanced oil recovery there's capacity for about 83 gigatons. At current emissions from North America, that would be about 12 years.

Mr. HAWKINS. Senator, if I might just add our own view. Capacity is not the constraint, there is adequate capacity. Technology is not the constraint, nor is understanding of feasibility the constraint. Both the IPCC and the MIT study concluded that we know enough about the geology of these formations to safely store millions of tons a year in individual projects.

What the demonstrations will accomplish is getting hands-on experience out of the oil industry and into the power sector industry. The oil industry knows how to do this stuff. The oil industry understands the geology. This is not a question of sort of experimenting and sticking a well in somewhere and saying, "Well gee, now we'll see whether it works or not." When that well is drilled, the companies that operate it will know the CO_2 is not going to leak out. The pathways that are the most risky are other wells that have been drilled into the formation because they form a potential pathway.

So, the understanding is very clear. What the industry will do before going into a formation is they'll do a survey, they'll find that the cap rock is thick, they will survey the cap rock to make sure that there are no natural fractures or faults that could be a pathway, and then they will survey the location of any wells, and evaluate the integrity of the cement to make sure that it can not become a pathway. This is well understood as to what needs to be done. So, this is not a matter of guesswork.

Senator KERRY. So, what in your judgment, what's the delay factor here, in your judgment, Mr. Hawkins? Why aren't we moving full speed ahead?

Mr. HAWKINS. Well, we have frankly been schizophrenic about the need to attack the global warming problem and we are now approaching the point where the U.S. is about to get serious in doing it. And, I think, you know, frankly, the industry has been schizophrenic as well, and all of that has lead to delay.

But, I—Senator Ensign asked the question about how much would it cost to do a couple of these projects, and the answer was it, you know, might take $2 billion.

But to put that in perspective, the kind of policies to cap and trade carbon dioxide emissions that are being discussed, will generate enormous amounts of resources that can be deployed to accelerate the deployment of this kind of technology.

For example, in the Lieberman-Warner bill, there is a provision that provides subsidies for going ahead quickly with carbon capture and storage, and the funds in that provision alone are on the order of $3 to $5 billion a year for 10 years.

Senator KERRY. It's a big pot. Well, we're trying to win some votes.

Mr. Childress, what—you emphasized the need to develop these plants. What do you think would be the best support structure, how could we most rapidly accelerate this effort?

Mr. CHILDRESS. The first thing that industry needs is predictability in public policy. The investment community needs the same thing. They have to know that there are rules out there and if they follow those rules and make a prudent investment, they will get a return.

Now, we don't have a price on carbon, it gets down to some sort of cost-sharing to get the first adopters in place. And it has to do with legal issues such as liability. Once you put that——

Senator KERRY. You would concur that cap-and-trade, in effect, is a pricing of carbon?

Mr. CHILDRESS. I will say whatever puts a price on carbon, and if that price is such that it will convince investors, if they build an IGCC or and SNG plant with CCS; and, they will get a return, that will work.

Senator KERRY. Understood.

Well, this has been very helpful and I appreciate the creation of this record. Is there anything anybody feels they wanted to say that they haven't had a chance to? It's a wise panel.

[Laughter.]

Senator KERRY. So I'm going to leave the record open for 2 weeks in case any of our colleagues want to submit any question to you in writing. And I'm very, very appreciative to you for taking time to come here today, helping us formulate this. We've got a long way to go and we've a very short time to do it, this has been helpful. Thank you.

We stand adjourned.

[Whereupon, at 4:08 p.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF HON. TED STEVENS, U.S. SENATOR FROM ALASKA

Mr. Chairman, thank you for holding this hearing today on coal gasification.

In the United States alone, coal-fired power plants satisfy more than half of the Nation's energy needs and this percentage is likely to increase in the future. Coal is both abundant, inexpensive, and represents one of our most important natural resources.

It is a stable commodity and a key component in satisfying the United States' growing energy demands. Coal production is an important element to our national security. Without it, we would be increasingly reliant on unstable or unfriendly nations for our energy needs.

Continued reliance on imported energy from volatile regions of the world is not a solution. We must increase our domestic production in order to remain globally competitive and we must do so in an environmentally responsible manner.

New technologies to make this possible are on the horizon. Carbon capture and sequestration is just one of many processes already in development. Groundbreaking research is being conducted to develop new ways to burn coal in order to maximize energy yield and employ cleaner and more efficient processes.

One of these processes is the Integrated Gasification Combined Cycle or IGCC. The IGCC process is a promising new technology, which has the potential to increase efficiency by 40 percent.

However, I understand that this process is not conducive to all regions because of its limitations on the type of coal, which can be used. Solutions must be found that will accommodate the local needs and we must continue to research and develop other methods.

I believe that in order to reduce our impact on the environment while still providing the energy necessary to fuel our economy, we must take steps to find a technological solution and make clean coal a reality. This is why I am a cosponsor of Senator Kerry's clean coal demonstration bill. S. 2323 would require the Secretary of Energy to establish a competitive grant program to provide assistance for commercial demonstration projects for the capture and sequestration of carbon emissions from coal-fired power plants.

As we move into the future, many different types of energy technology must be used in order for this Nation to remain competitive and secure. Coal will continue to be the backbone of our Nation's energy supply, and we must develop ways to use it in an efficient and clean manner.

I look forward to hearing today's testimony.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. JOHN F. KERRY TO DR. JOSEPH P. STRAKEY, JR.

Question. Could you please provide clarification on the analysis you mentioned during oral testimony in regards to the cost of implementing CCS nationwide by 2030.

Answer. National Energy Technology Laboratory (NETL) examined a United States policy scenario that applied a tax of $30 per metric ton of carbon dioxide from 2015 to 2030. Projections were based upon cost and performance assumptions consistent with the U.S. Energy Information Administration's 2007 Annual Energy Outlook. Cost and performance for retrofitting the existing fleet of pulverized coal (PC) power plants was based on a recent NETL study (*Carbon Dioxide Capture from Existing Coal-Fired Power Plants,* DOE/NETL–401/110907, revised November 2007).

The analysis projected that 40 gigawatts (GW) of new advanced coal-fueled power plant capacity would be deployed with carbon capture and sequestration (CCS). It also projected that 100 GW of existing PC net power plant capacity would be retrofitted for CCS through 2030. However, the parasitic energy consumed by the CCS equipment would reduce the total net output of these plants to 70 GW (a reduction of 30 GW-net).

The cost of constructing 40 GW of new coal-fueled power plant capacity with CCS is estimated to be $140 billion (2007-year dollars), including owner's costs but excluding allowance for funds used during construction. Twenty-eight percent, or $40 billion, of the total construction cost is attributable to adding CCS. This estimate assumes that the new advanced coal plants are Integrated Gasification Combined Cycle (IGCC) plants with a capital cost of $3,500/kilowatt (kW), of which $970/kW is attributable to CCS. (If CCS was not applied to the 40 GW of new IGCC power plants, their net capacity would be increased by 15 percent, or 6 GW.)

The "overnight" cost of retrofitting 100 GW of PC power plant capacity for CCS is estimated to be $95 billion (2007-year dollars). Retrofit costs ($955/kW of pre-retrofit capacity) were escalated from July–2006 dollars to October–2007 dollars using Chemical Engineering's Plant Cost Index. If the resulting reduction in capacity (30 GW-net) was replaced by new IGCC plants with CCS, the replacement cost would be $105 billion.

The total cost of CCS for both the new and retrofitted capacity would be $240 billion (2007-year dollars). The avoided carbon dioxide emissions for the 40 GW of new IGCC amounts to approximately 189 million metric tons/yr; for the 100 GW of retrofitted PC plants, the avoided CO_2 amounts to approximately 550 million metric tons per year (including the CO_2 emitted by the 30 GW of IGCC replacement power equipped with CCS).

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