The Carbon Capture and Storage Imperative

Recommendations to the Obama Administration's Interagency Carbon Capture and Storage Task Force

John Thompson
Kurt Waltzer
Mike Fowler
Joe Chaisson

July 1, 2010

Founded in 1996, the CATF is a nonprofit organization dedicated to reducing atmospheric pollution through research, advocacy, and private sector collaboration.

MAIN OFFICE

18 Tremont Street
Suite 530
Boston, MA 02108
617.624.0234
info@catf.us
www.catf.us

Table of Contents

Summary

The Earth's climate is warming significantly. The world's oceans are also warming, as well as acidifying, threatening populations of microscopic animals that are the basis of the ocean's food chains. If greenhouse gas (GHG) emissions continue, Earth's climate could pass critical tipping points such as unstoppable melting of the Greenland ice sheet and attendant sea level rise.

The implications of these facts are stark: Global carbon dioxide (CO_2) emissions must be eliminated by mid-century to avoid the worst impacts of further warming. This extraordinary challenge must be met despite increasing demands for energy driven by very large increases in global populations and economic activity in the next four decades.

Although the climate challenge is complex and multi-faceted, no single issue is more central to it than the future of coal. Burning coal generates 40 percent of the world's energy-related carbon dioxide emissions today—and more than 40 percent of the Earth's electricity.

Despite coal's catastrophic costs, it would be unrealistic to hope it might simply go away. To the contrary, coal usage is growing globally at a staggering rate. China alone has built a coal fleet as large as the entire U.S. coal fleet over the past five years, and it may grow to 1,000 GW, three times the size of the U.S. coal fleet, by 2015. Equally important: Even if coal were entirely replaced with cleaner natural gas, CO_2 emissions would drop by only 50 percent, not enough to avert significant climate dangers.

It would be no exaggeration, therefore, to say that the fate of the global climate may hinge upon the question of coal. If we can find a way to burn coal cleanly—without emitting CO_2—then we might still meet the climate challenge successfully; if we cannot, there is little hope for success.

Understanding—and realizing—the full potential of carbon capture and storage (CCS) is consequently a task of the highest national importance. The question before us now is how to design a comprehensive, multi-decadal effort to accomplish it.

Over the past decade, the role of CCS in meeting CO_2 abatement goals has been extensively studied by many groups, including the Intergovernmental Panel on Climate Change (IPCC), the International Energy Agency (IEA), the U.S. Department of Energy (DOE), the Massachusetts Institute of Technology (MIT), and the Electric Power Research Institute (EPRI). These studies demonstrate that without the use of CCS, the cost of achieving atmospheric stabilization for a range of scenarios would increase 50 to 80 percent. Furthermore, absent CCS, it would be extremely unlikely that stabilization below 550 ppm could be achieved.

Despite the importance of CCS, it has an orphan-like status among climate abatement options. Coal companies and utilities generally support CCS demonstrations, but many resist policies that would implement it at large scale. Environmental groups often oppose the technology because they fear it will enable continued dependence on coal. And environmentalists who do support CCS often consider it a low priority compared to energy efficiency and renewable energy.

While federal CCS expenditures grew significantly in the stimulus package, federal spending on CCS is only around $8 billion, a fraction of what is needed to build enough CCS projects to eliminate technical uncertainties. Current federal policy is not sufficient to lay the groundwork for a coherent, long-term effort to deploy CCS at sufficient scale to reduce CO_2 emissions significantly.

To develop recommendations for President Obama's Interagency Carbon Capture and Storage Task Force, the Clean Air Task Force (CATF) drew upon several sources of expert knowledge in this field. CATF has years of experience working with developers of coal- and petcoke-based CCS projects in the United States and China. This work has helped shape our international perspective on CCS and helped us understand the barriers that pioneer projects face. We also examined state incentive programs which have played a key role in advancing some projects in the United States, and compared them to federal incentive programs. And we drew upon the recommendations for CCS research and development presented in *Coal Without Carbon*, a 2009 CATF report written by prominent academic and industry experts.

We also retained the NorthBridge Group, a respected consulting firm, to model various potential CCS policies using a unit-by-unit dispatch model of the coal fleet in the eastern United States. We used this modeling to estimate the size of incentives needed to install CCS, the impact of reverse auctions to allocate federal funds, and the effects of potential CO_2 performance standards for power plants.

From this work, a picture emerged that highlighted the need to deploy CCS early. Not only would early deployment achieve significant emissions reductions sooner, but it would help avoid a potential problem that emerged in our modeling: If, by 2040, uncontrolled natural gas replaces coal, massive CO_2 reductions will still be needed but the CCS pipelines and storage sites needed to accomplish this dramatic change by 2050 would not be in place. Our analysis showed that these barriers and problems can be overcome, but not without careful understanding of the policy instruments needed to develop the CCS industry in a timely and effective manner.

To understand these challenges, it is helpful to think of the development of the CCS industry as moving through three key phases:

- **The pioneer phase**, during which enough projects are built (about thirty) to *eliminate technical uncertainty*.

- **The cost reduction phase**, during which enough projects are built (about 50 GW) to *reduce costs* by traversing learning curves, expanding infrastructure such as pipeline and storage sites, and creating new institutions to support CCS growth.

- **The mature industry phase**, during which the industry expands to *a scale that makes deep reductions in carbon dioxide emissions possible* by mid-century.

This progression is depicted in the chart below:

Since the barriers limiting development will differ in each phase, the actions required will also differ. CATF's recommendations focus on the first two of these phases, since that is where the principal barriers of immediate concern lie.

Pioneer Phase Recommendations

The key barriers in the pioneer phase are economic and technical. Our key recommendations for this phase include *a $20 billion plan* to do the following:

1. *By 2018, build a portfolio of CCS projects* that includes:

   - 4 GW of coal-based post-combustion capture (PCC)
   - Nine pre-combustion capture coal/petcoke plants, including IGCC, SNG, and other gasification industrial products
   - Three commercial-scale underground coal gasification (UCG) plants
   - One post-combustion capture natural gas plant
   - An expanded CO_2 pipeline network
   - Commercialization of up to five saline formation injection sites (injecting around 5 million tons of CO_2 per year for five years)

   This portfolio differs from other proposals in important respects:

   - It is about *three times the size* of the 5-10 project goal described in the president's February 3, 2010, memo establishing the Interagency Task Force.
   - It includes *natural gas CCS*.
   - It includes *UCG with CCS*, a technology that, once demonstrated and commercialized, could be the most affordable method of CCS, with significant potential for use in countries like China and India.

   Our report identifies more than twenty domestic CCS projects under development and suggests practical approaches to bringing them into operation.

2. *Expand the current regional transport and storage system* by:

   - Characterizing ten to twenty saline sites
   - Expanding CO_2 pipeline networks to connect existing enhanced oil recovery sites with other regions
   - Conducting a systematic review of potential offshore saline reservoirs

The $20 billion cost of this initiative is comparable to the investment the United States has made in recent years in wind energy. We identify three options for financing this effort, including revenue from a national wires charge, purchase of electricity from CCS through a national portfolio standard, and expanding tax incentives.

We also identify other actions that could be taken with existing authority and appropriations, including:

- Using $1 billion in existing appropriations to install CCS at the Edwardsport, Indiana, IGCC plant currently under construction
- Developing FutureGen through DOE electricity purchase agreements
- Waiving DOE cost-sharing requirements for early post-combustion capture plants
- Using Clean Air Act regulatory authority to require adoption of CCS technologies under BACT provisions.

Cost Reduction Phase Recommendations

In this phase, cost is the key barrier to building 50 GW of coal and natural gas plants with CCS and expanding CO_2 pipelines and injection storage sites. CATF estimates the cost of incentives needed in this phase to be $275 billion over several decades.

Our recommendations highlight several policy ideas, including:

- Using a reverse auction as the method to distribute financial incentives. This would award contracts to the lowest bidder, ensuring that funds are used efficiently and that enough projects are built.
- Establishing performance standards for new and existing coal and gas plants sufficiently stringent to drive deep reductions in CO_2 in the coming decades.
- Developing new institutions to facilitate CCS industry growth, including geologic sequestration utilities (GSUs) to secure sufficient saline formation injection capacity for a growing CCS industry.

CATF makes nineteen specific recommendations in the report, which are summarized in the table on the following pages.

Clean Air Task Force Recommendations	Page Number	Task Force Subgroup
General		
The Obama administration should develop by 2018 a portfolio of CCS projects that includes 4 GW of post-combustion capture; 3 underground coal gasification projects; an expanded CO_2 pipeline network; 9 commercial-scale surface gasification projects, including IGCC, SNG, and other industrial plants; and 5 saline formation injection sites.	35	CCS Deployment Drivers and Incentives
Provide $350 million in federal funding to characterize 10–20 saline sequestration sites in 2011–2012.	40	CO_2 Storage/Reuse
Establish a federal program to create regulated public utilities to facilitate geologic carbon sequestration.	52	CCS Deployment Drivers and Incentives
Incentives and Other Funding		
The Obama administration and Congress should increase incentives for pioneer phase projects by $20 billion. Funding alternatives include:	38	CCS Deployment Drivers and Incentives
1. *Enact a wires charge to fund $20 billion worth of pioneer projects.*		
2. *Expand the clean energy standards contemplated in various energy bills to include buying electricity from CCS projects.*		
3. *Enact a package of incentives that collectively could complete the pioneer phase projects*. Options would include loan guarantees, a production tax credit for SNG, a CO_2 sequestration credit, accelerated depreciation, and increased CCPI funding.		
The administration should support efforts in Congress to create a significant CCS deployment financial incentives package worth $275 billion that would drive 50 GW of CCS beginning around 2020, using a reverse auction mechanism.	51	CCS Deployment Drivers and Incentives
Performance Standards		
In the absence of legislation, EPA must propose in spring 2011 (and finalize by 2012) *GHG emissions performance standards for*	51	Regulatory/ Legal

new coal plants under Clean Air Act section 111(b).		
In the absence of legislation, EPA must propose in spring 2011 (and finalize by 2012) a *GHG emissions performance standard for new natural gas power plants* under Clean Air Act section 111(b), based on emissions levels that can be reached through application of CCS.	52	Regulatory/ Legal
In the absence of legislation, EPA must propose in spring 2011 (and finalize by 2012 and direct states to implement) a program of *GHG emissions performance standards for existing coal and gas plants* under Clean Air Act section 111(d), based on emissions levels that can be reached through the application of CCS.	52	Regulatory/ Legal
Actions That Can Be Taken Under Existing Authority		
DOE should use $1 billion in stimulus money to fund a 65 percent capture CCS project on the Edwardsport IGCC plant in Indiana. This 630 MW project is already under construction and is pursuing CCS.	36	CCS Deployment Drivers and Incentives
President Obama should direct EPA to include, in January 2011 Clean Air Act guidance, regulatory incentives for BACT standard setting for new and modified major sources, based on the deployment of CCS technologies, in cases where there is potential for at least partial emissions control through deployment of CCS. The administrator should make changes to the existing PSD permit innovative technology waiver to make it more attractive to project proponents who want to use CCS to make deep reductions in CO_2 emissions at major new and modified stationary sources.	36	Regulatory/ Legal
The president should direct DOE and/or other federal agencies to purchase the electrical output from FutureGen. Purchasing the electrical output would allow the project to operate for twenty years or more.	37	CCS Deployment Drivers and Incentives
The secretary of energy should waive the 50 percent cost-sharing provisions for pioneer post-combustion capture projects. Given unique PCC circumstances in this phase,	37	CCS Deployment Drivers and Incentives

federal support must pay *almost all* of the cost of the demonstrations.		
DOE and IRS should work together to ensure that projects can be eligible for multiple credits. For example, while federal law does not prohibit projects from obtaining both 48A and 45Q incentives, IRS could opt to limit projects to receiving one or the other.	38	CCS Deployment Drivers and Incentives
International		
The federal government should create a $500 million CCS Deployment Fund, to be spent over five years, to support U.S. companies' participation in the CCS partnerships with companies in China.	55	CCS Global Initiatives
Research & Development		
Federal research must establish a 10-year, advanced PCC technology RD&D pipeline supporting bench-scale research, proof of concept systems, and pilot-scale plants.	57	CO_2 Capture
Establish a federal program to develop UCG process simulation, monitoring tools, and testing	58	CO_2 Capture
Establish a publicly funded GCS testing facility, costing $200 million over 4 years.	58	CO_2 Storage/ Reuse
Provide $10 million for a DOE/DOI assessment of offshore geologic storage potential.	40	CO_2 Storage/ Reuse
Other Actions That Should Be Taken in Conjunction with Congress		
Provide funding for formalization of the cross-fertilization between EPA's air and water offices, and the cultivation of additional in-house experience with CO_2 sequestration technologies, geologic media, and permitting in consultation with NETL and USGS. EPA should create a new division dedicated to CO_2 sequestration and permitting reviews, and related permitting issues.	40	Other

Climate Change and the Importance of Carbon Capture and Storage

The Earth's climate is changing. Since the beginning of the Industrial Revolution, global average temperatures have increased by about 1.5 degrees Fahrenheit. Polar ice is melting at an alarming rate; glaciers and ice sheets are retreating worldwide, and ecosystems are already experiencing significant effects. Oceans are warming and acidifying, threatening populations of microscopic animals that are the basis of the ocean food chains.

Human activities—primarily, the burning of fossil fuels for energy—are the predominant cause of these changes. In the past 300 years, human activities have released more than 1.5 trillion tons of carbon dioxide and other greenhouse gases into the atmosphere. Because the natural processes that remove CO_2 are slow, most of these gases will persist for centuries.

The warming effects of CO_2 and other human activities are almost certain to cause global temperature increases of more than 2 degrees Celsius from pre-industrial times. Although the risks are unquantifiable, there is real danger that the Earth's climate could, at some point, pass critical tipping points (such as unstoppable melting of much of the Greenland ice sheet), with profound consequences.

The implications of these facts are stark: Global CO_2 emissions must stop by mid-century to avoid the worst impacts of further warming. Achieving that goal will require extraordinary efforts on many fronts, but no single issue is more central to this challenge than the problem of CO_2 emissions from coal.

Coal releases about 40 percent of the world's energy-related carbon dioxide emissions, produced while generating more than 40 percent of the Earth's electricity. Coal's costs, both human and environmental, are consequential—yet coal persists, due to its abundant supply and low cost. Coal is not going away; to the contrary, coal usage is expected to double over the next thirty years as China, India, and other emerging economies grow.

In the United States, we burn more than three tons of coal per person per year to generate electricity, supporting a high standard of living. The combined population of China and India is eight times larger than America's, yet they consume only 15 percent as much electricity. Americans consume nearly seven times as much energy as the average Chinese or Indian. That cannot continue. Asian economies are booming, and electricity generation is skyrocketing. China alone will build more than a thousand new coal-fired power plants in the coming decades.

Left unchecked, coal's CO_2 emissions will make it impossible to avoid the worst impacts of climate change. Even if coal were entirely replaced with cleaner natural gas, CO_2 emissions would drop by only 50 percent—not enough to meet emissions targets. There is no solution to climate change, therefore, without a solution to coal's CO_2 emissions. Carbon capture and storage (CCS) is clearly an essential element of any realistic carbon abatement strategy.

CCS is not a single technology; it is a group of processes—capture, transport, and storage—that in concert can isolate carbon dioxide from the atmosphere. Its key advantage is its potential ability to be deployed on a scale that can feasibly eliminate CO_2 emissions from coal.

Three important facts about CCS to consider:

- The use of CCS would *lower the total societal cost of addressing climate change by approximately 30 percent*.[1] That is, without CCS, more costly methods will be needed to meet emissions targets, which could add trillions of dollars to the cost of compliance.[2] CCS, in other words, may be the key to achieving large-scale emissions reductions at a socially acceptable cost.

- *CCS will not be widely used until carbon dioxide is regulated*. CCS has only one purpose—compliance with environmental standards—and its costs, even when optimized, will never be trivial.

- *Implementing CCS will require the creation of an entirely new industry* on a massive scale to capture, store, and inject carbon dioxide deep underground. This is not simply a question of adding a device such as a scrubber to a plant.

This report is focused on that last point—the need for a new industry to emerge in order for CCS to play a meaningful climate protection role. This report describes what steps federal policymakers must take in the short and medium terms to create a new CCS industry, emphasizing recommendations that the Interagency Carbon Capture and Storage Task Force could make to create commercial CCS demonstrations in the next few years and, subsequently, to develop these pioneering projects into the next stage of an early CCS industry.

---

[1] Intergovernmental Panel on Climate Change. 2005. "IPCC Special Report on Carbon Dioxide Capture and Storage: Summary for Policymakers." http://www.ipcc.ch/pdf/special-reports/srccs/srccs_summaryforpolicymakers.pdf

[2] James Dooley. 2006. "Macro and Micro: The Role for Carbon Dioxide Capture and Geologic Storage in Addressing Climate Change." Presentation for the Joint Global Change Research Institute. http://powerpoints.wri.org/ccs_dooley.pdf

The Development Phases of the CCS Industry

Over the past year, CATF developed a framework for explaining how a new carbon capture and storage (CCS) industry could be developed in the coming decades. This model of the industry evolved from our work with CCS project developers, new economic modeling (including dispatch models of each coal unit in the eastern U.S. power system), and analysis of previous technology innovation in the power sector, such as sulfur dioxide scrubbers.

We believe that the CCS industry must grow through three distinct phases, and that federal policy should be designed to drive progress forward at each phase. The initial pioneer phase should seek to eliminate *technical* uncertainties involved in CCS; in the subsequent cost reduction phase, *costs should fall* as a result of learning from deployment. Finally, in the mature industry phase, CCS would be *scaled up* to a level that would meet climate protection objectives. These phases are depicted in the graphic below:

During the pioneer phase, the focus should be on eliminating technical barriers to efficient commercial-scale CCS. This should include:

- Removing scale-up barriers in post-combustion capture technology so that it can be applied with warranties on full-sized coal and natural gas plants

- Eliminating integration barriers on the gasification plant (where carbon capture technology has been commercially available for decades) and the power island

- Scaling up saline storage to commercial project size

- Developing underground coal gasification more widely in the West to provide investors with greater confidence in the technology

These technical barriers can be overcome with a relatively small number of projects, but few investors want to build first-of-a-kind projects. Not only is there a danger from an investor's perspective that the projects won't perform properly from the outset, but they certainly will cost more the fifth or sixth time the technology is implemented. And, while investors are sometimes willing to lose money on the first project, they need confidence that there will be markets in the future that will reward them for their early investment. Policy must reduce the penalties against pioneer projects enough to make them attractive, given the potential for early adopters' rewards. This generally means subsidizing some or all of the risk for these projects through state and/or federal incentives.

After the pioneer projects, the cost reduction phase would entail a large expansion in the number of CCS projects in the United States—perhaps by as much as 50 GW or more. This expansion would:

- Drive down costs, as the CCS industry moves up the learning curve

- Expand the initial pipeline and CO_2 injection site infrastructure

- Create new engineering and manufacturing knowledge and new public and private institutions to facilitate growth of the industry

During this phase, the cost of sequestration could fall by 25 percent or more.

Once the technology is mature and the economic and regulatory framework for the industry is well established, CCS would be prepared to move into the mature industry phase, which would be designed to produce the deep emissions reductions that are needed by mid-century.

This phased development and deployment of CCS should not be seen as a reason to delay climate legislation or the imposition of carbon reductions standards; waiting will not increase the readiness of CCS or lower its cost. To overcome technical and economic CCS barriers, timely federal action is required. By carefully designing policies that move CCS through these phases in a coherent, effective, and efficient manner, the overall societal costs of stabilizing atmospheric CO_2 concentrations can be lowered.

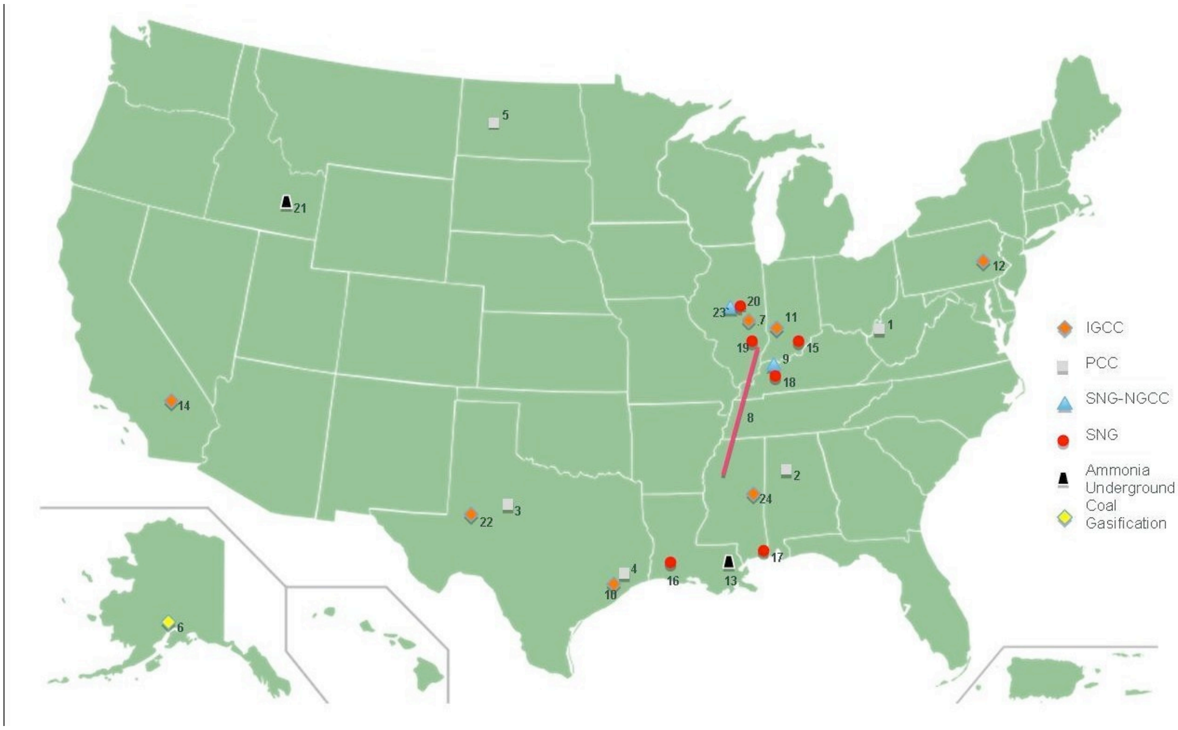
Coal with CCS Projects in Advanced Development

CATF estimates that there are about twenty to twenty-five commercial-scale CCS projects in advanced stages of development that utilize coal or petcoke; these projects are identified in table 1 below. These projects constitute the bulk of the first wave of potential pioneer projects. Other pioneer projects that focus more narrowly on saline injection or EOR are identified in table 2.

Table 1

Proposed U.S. CCS Projects Fueled by Coal and/or Petroleum Coke	
Post-Combustion Capture	
1	AEP, Mountaineer, PCC Retrofit, WV
2	Southern Co., Plant Barry PCC retrofit, MS
3	Tenaska, New PC-Post combustion, Sweetwater, TX
4	NRG, Washington Parish Plant, PCC Retrofit, SW of Houston, TX
5	Basin Electric, Antelope Valley, PCC Retrofit, ND
Underground Coal Gasification	
6	CIRI, Anchorage, AK, UCG IGCC with CCS
CO_2 Pipelines	
8	Denbury, Midwest EOR Pipeline
Surface Gasification	
9	Cash Creek, SNG and Electricity, Henderson, KY
7	FutureGen, IGCC with CCS, Mattoon, IL
10	ConocoPhillips, IGCC, Sweeny, TX
11	Duke, Edwardsport, IGCC, IN
12	Future Fuels, IGCC, Good Spring, PA
13	Faustina Hydrogen Products, Ammonia, St. James Parish, LA
14	Hydrogen Energy, IGCC w/ CCS, Kern County, CA
15	Leucadia, SNG, Rockport, IN
16	Leucadia, SNG, Lake Charles, LA
17	Leucadia, SNG, Moss Point, MS
18	Peabody SNG, Central City, KY
19	Powerholdings, SNG, Mt. Vernon, IL
20	Secure Energy, SNG, Decatur, IL
21	SEI, Fertilizer, American Falls, ID
22	Summit, IGCC, Odessa, TX
23	Tenaska, SNG and Electricity, Taylorville, IL
24	Southern Co., IGCC, Kemper County, MS

The map shows the locations of these projects.



From our work with developers and government officials and from modeling analysis, we have drawn several conclusions about the state of these projects:

1. **The federal government will need to provide significant additional incentives to build CCS projects**. States are providing significant funding for new coal and CCS projects, but the federal government will need to help fill the gap in cost between building a first-of-a-kind coal plant with CCS today and the most economic alternative for providing electricity (an uncontrolled natural gas combined-cycle plant).

2. **Many CCS projects today are primarily underwritten by state governments, which have taken a leadership role in areas where federal support has been lacking.** The total federal support for CCS incentives is around $8 billion,[3] and no single project has received more

[3] This takes the form of grants (maximum per project is about $350 million), loan guarantees ($2 billion–$3 billion per project, at a cost to the federal government of a few hundred thousand per project, assuming no default), and assorted tax credits (total value of about $300 million per project).

than $500 million in federal funds. In contrast, states have provided (or are considering providing) several billion dollars worth of support per project, largely by allowing projects to be placed into the rate base and paid for by customers. For example, within the next six months, Illinois will decide whether to rate-base the Taylorville Energy Center with CCS. This decision is worth $5 billion–$11 billion over thirty years to the project ($1.6 billion–$3.6 billion in 2010 dollars). Other examples include:

- Duke, Edwardsport IGCC: The Indiana Utility Regulatory Commission voted in 2007 to place the project into the rate base of consumers in Duke's service territory.
- Southern Power, Kemper IGCC: The Mississippi Public Utilities Commission recently voted to place the project into the company's rate base.
- Hydrogen Energy, Kern County IGCC: California regulators will consider a proposed power purchase agreement in the fall of 2010 that would provide cost recovery for the project.
- FutureFuels IGCC, Good Springs, PA: This project will receive special treatment under Pennsylvania law for electricity sales.
- Leucadia SNG project, Rockport, IN: Indiana law allows this project to sell all of its methane to the state, enabling the project to be financed if the state contract is signed.

A key exception to this trend is post-combustion capture retrofits. These projects do not produce revenue for project sponsors the way new generation projects with CCS do. They are also much less likely to receive state public service commission approval for rate basing because they are not required to meet current environmental laws; they would also reduce the plant's electric output and involve technical risks. For this technology, special federal support for pioneer projects is essential (more on this in the next chapter).

3. **Most of these CCS pioneer projects have reached a tipping point: Many will either break ground in the next eighteen months or they will be cancelled.** This reflects the fact that many projects have simply reached an advanced stage of development; they have permits that will expire if they do not move forward with construction.

4. **Many projects use enhanced oil recovery (EOR) as the CO_2 storage medium to lower costs.** EOR has the advantage that *CO_2 has been routinely purchased and injected with near 100 percent retention for decade*s, but the value of CO_2 purchased for EOR is insufficient to offset the cost of CCS. This tends to limit project development to areas

where EOR is already established—Texas and the Gulf Coast, some small parts of the Midwest, parts of Canada (especially Alberta), and parts of the Interior West. Developers in areas that are not served by EOR, such as the larger part of the Midwest, are working to develop CO_2 pipelines to connect their projects to existing EOR resources in the Gulf States.

5. **Many projects are polygen plants.** These plants generate revenue from more than electricity. By selling fertilizer, natural gas, or transportation fuels derived from coal, these projects lower the revenue requirement from electricity generation. And since the carbon capture is part of the process of making the polygen product, there is no cost for the capture.

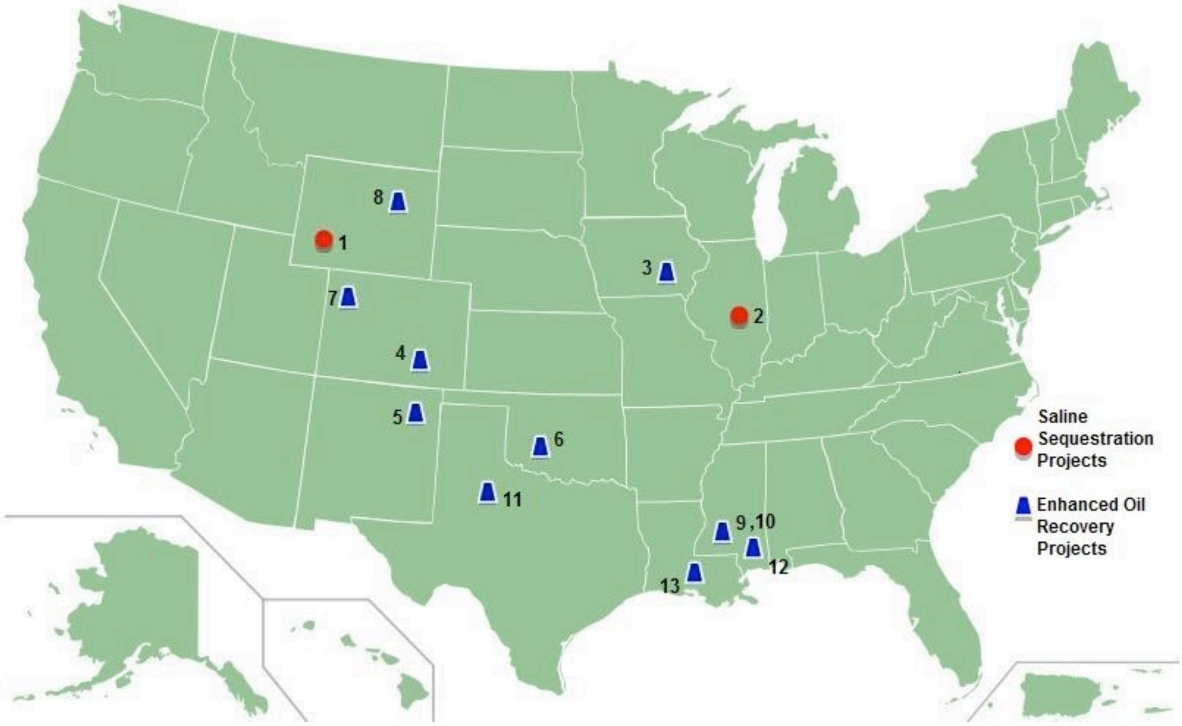
6. **Some projects use novel technologies to lower overall costs.** These projects, such as underground coal gasification, could potentially lower production costs, including CCS, to the level of an uncontrolled coal plant. However, these technologies involve other technological risks, which are described in the following chapter.

There are also a number of projects that propose to sequester CO_2 from existing sources, either to demonstrate saline sequestration or to generate revenue from EOR. These projects are identified in table 2 and the accompanying map below.

Table 2

Planned U.S. Saline Sequestration Projects and Enhanced Oil Recovery Projects				
Saline Sequestration Projects				
Key	**Project**	**Plant**	**Company**	**Injection Amount (tonnes/day)**
1	Big Sky Injection of CO_2 into Moxa Arch	Petroleum or Natural Gas Facility	Montana State University	2,740
2	MGSC Large-Volume Sequestration Test; Ethanol Plant Source	ADM Ethanol Facility	Illinois State Geological Survey	1,000
Enhanced Oil Recovery Projects				
3	University of Utah Industrial CCS Project	Coffeyville Resources Fertilizer Plant & Others	Blue Source	2,740
4	La Veta NG Processing	La Veta NG Plant	Blue Source	1,370
5	Pecos County, TX; Gas Processing	Century Gas Processing Plant	Occidental Petroleum	24,660
6	Purdy, Sho Vel-tum EOR	Fertilizer Plant	Andarko Petroleum Corporation	1,918
7	Rangely-Webber EOR	LaBarge Natural Gas Processing Facility	Chevron	3,562
8	Salt Creek, Monell, Sussex EOR	Commercial Source	Andarko Petroleum Corporation	5,480
9	SECARB Early Test	Jackson Dome	Southern States Energy Board	4,110
10	SECARB Gulf Coast Stacked Storage Project	Jackson Dome	Southern States Energy Board	1,242
11	SWP SACROC EOR Project	McElmo Dome		822
12	Praxair Inc. CO_2 Capture and Sequestration Project	BP Refinery and Hydrogen Production Facility	New Mexico Institute of Mining & Technology	2,740
13	Shell Chemical CCS Project	Multiple	Praxair	2,740

Source: NETL Carbon Capture and Storage Database



As the table suggests, most of these projects use existing sources of high-purity CO_2; typically, the CO_2 must either be purchased or brought to the site.

Barriers to Carbon Capture and Storage

The largest barrier to deploying carbon capture and storage is economic. CCS will not be deployed until regulations or legislation create a sufficient incentive to do so. To estimate the size of the economic barrier, CATF estimated the costs to install CCS in two of the three CCS development phases:

- *Pioneer phase: Building around twenty-five coal/natural gas-with-CCS projects and five saline injection sites by 2018*. CATF estimates that the federal government will need to provide $20 billion in incentives to complete these projects. The purpose of these pioneer projects is to reduce the *technical risks* associated with commercial-scale CCS.

- *Cost reduction phase: Establishing the first 50 GW of coal with CCS*. CATF estimates the cost for this phase would be $275 billion in nominal dollars over the coming decades. The purpose of building the first 50 GW is to significantly *lower the costs of CCS* below those experienced in the pioneer phase.

These economic barriers could be overcome by a combination of incentives (both state and federal), and policies that constrain carbon emissions such as caps and/or GHG performance standards.

Other barriers, particularly in the pioneer phase, are also important. For investors, *technical uncertainty* raises the costs and performance risks of first-of-a kind projects. These uncertainties also make it difficult for policymakers to determine which capture technologies have the most promise and assess how they compare to other mitigation options over the next several decades.

Lack of infrastructure is also a key barrier for pioneer phase projects. Developers that want to capture CO_2 can't be financed because there is no place to store the CO_2, and sequestration sites cannot be built because capture is not occurring. This "chicken-egg" problem must be addressed.

The barriers to CCS are not static, although it is hard to predict how quickly or how much they will change. Today, the absence of regulations or laws that drive CCS is a major barrier to deployment. Without new laws, CCS and its component technologies will only be used sporadically and in niche applications. Technological barriers are also not static. Within a decade, technology-based CCS barriers may diminish as more experience is developed.

Barriers in the Pioneer Projects Phase

Why would any developer of a coal or petroleum coke project consider adding costly CCS to a new facility if current laws don't require it?

In some instances, CCS may be advantageous for plants seeking financing. Investors need to have a reasonable expectation of earning an acceptable return on a major capital investment, despite the uncertainty about carbon regulations and pricing. Developers may conclude that their investors will not risk several billion dollars on a new, multi-decade energy project that entails high CO_2 emissions; CCS could therefore reduce the risk of the investment by hedging against the risk of future emissions limits.

In other cases, a utility (or competitive generating company) may have a fleet of existing coal plants that will one day need to be retrofitted or retired. By undertaking a CCS retrofit project, the company could learn enough to make better investment decisions, reducing future compliance costs.

In both instances, these pioneer phase projects face the same challenge: how to turn uncertainties and penalties for those that adopt new and innovative technology into early rewards for investors and shareholders. While there are a host of barriers facing projects, this section focuses on the three largest ones: economics, technology, and infrastructure.

Economic Barriers to Pioneer CCS Projects

Pioneer projects must overcome fundamental economic challenges.

- Outside of EOR, carbon dioxide has no value today because carbon emissions are not regulated; CCS incurs net costs that competitors do not have to bear. Investors must weigh the uncertain long-term potential benefits of CCS against the concrete near-term costs of pioneer projects.

- First-of-a-kind projects are more costly than later projects. Later projects benefit from cost reductions that are possible when building the "nth" plant using the same technology.

- CCS projects involve a lot of steel and cement. In recent years, commodity prices have risen, briefly dipped, and now appear to be rising again. These price increases adversely impact CCS projects and increase cost-overrun risks. (This barrier is not inherent in the pioneer phase per se, but it does concern current projects.)

- Electricity demand in many parts of the country is lower than it has been historically, so new projects generally are sometimes difficult to justify. And where new generation is needed, there are many competing low-carbon alternatives, some of which (e.g., wind energy, nuclear power) are also receiving significant federal support.

Understanding the cost of CCS projects in different applications is critical to evaluating the extent of the economic barriers to early action.

To estimate the size of the economic barrier *for new fossil fuel projects with CCS*, the Clean Air Task Force examined cost estimates for recent projects provided by developers. In general, the incremental cost of incorporating CCS runs into billions of dollars for large projects. For example, the Taylorville Energy Center (50 percent CO_2 reduction achieved with SNG-NGCC technology) estimates the cost of the project's electricity over thirty years will be \$5 billion–\$11 billion higher than more polluting power, depending upon the regulatory and cost environment. In present dollars, that is roughly \$1.6 billion–\$3.6 billion, or *\$3,000–\$6,900 per Kw of installed capacity*.

To estimate the size of the economic barrier and the incentives required to overcome it *for PCC retrofits to existing coal plants*, the Clean Air Task Force commissioned an analysis from the NorthBridge Group, a leading economic consultant to electric utilities and competitive power generators. NorthBridge developed detailed estimates of the cost and performance effects of retrofitting existing coal units with today's "first-of-a-kind" CCS technology, capturing 90 percent of CO_2 emissions. These estimates were used to assess the overall cost and value of operating the retrofit unit with and without CCS. The estimates also reflected how the units would operate in their specific regional power markets.

This analysis was used to determine the level of subsidy that would be needed to make a unit's owner financially indifferent to retrofitting the unit with CCS. The results are expressed in dollars per KW of installed capacity and vary depending upon whether the plant is regulated or unregulated. Generally, the level of subsidy required for today's CCS technology applied to an existing pulverized coal unit (assuming there is no carbon price in effect) is about *\$3,400–\$4,300 per kW of installed capacity*. For a 1,000 MW plant, this is about \$3.4 billion–\$4.3 billion in today's dollars.

CATF estimates the economic gap that must be filled to build twenty-five coal/natural gas CCS projects and five saline sequestration sites by 2018 to be about \$43 billion. Based upon state incentives and expected private contributions, the federal share of this gap would need to be about \$20 billion.

Technological Barriers to Pioneer CCS Projects

First-of-a-kind projects are burdened by greater technological risks and uncertainties. There are several general concerns: 1) lenders and state public service commissions fear that the technology will not work as promised; 2) unplanned downtime may reduce projected revenues; 3) costs may rise if the plant operates less than anticipated and replacement electricity must be purchased; or 4) capital costs may be higher than expected if first-of-its-kind design work requires unplanned design changes. As described below, these issues vary by specific technology.

Post-Combustion Capture Technology Barriers

At small scales such as 100 MW, PCC on new plants or retrofitted to existing plants is technically feasible using processes and equipment available today. A number of vendors and EPC firms make "capture islands"[4] at this scale, and expect to offer standard commercial packages and guarantees for larger installations and/or installations with multiple parallel islands after they acquire initial operating experience at a smaller scale.

Technology risk for PCC retrofit is not limited to the PCC technology itself, however. Changes to the existing plant steam system are also likely upon retrofit.[5] Addition of SO_2 trim scrubbers and changes to other power plant equipment, such as the existing SO_2 scrubbers, may also be required. While the PCC vendor and EPC firms may provide limited guarantees of performance and cost for the PCC equipment island, they are unlikely to take responsibility for performance of the remainder of the power plant following retrofit. In the absence of state or federal assistance, power generation companies (and their customers and shareholders) would need to absorb the risks to performance (and revenue) of the existing asset following retrofit. Such risks are routinely taken by utilities when older power plants are rebuilt or modified, however.

There appears to be a critical size threshold around 100 MW equivalent (about 3,000 tons per day of CO_2 at 90 percent capture, or 1 million tons of CO_2 per year), above which the equipment needed for post-combustion capture in a commercial power plant is more likely to consist of multiple parallel equipment "trains." Consequently, this is a threshold above which PCC technology may be considered commercial scale, and below which it is not.[6] (This is an approximate calculation, however—the actual size threshold for a particular technology in a given instance may be half as large, or two or more times larger.) PCC plants in the 2–50 MW equivalent range are small-scale pilots constructed to obtain process data necessary for scaling up to full commercial scale.

---

[4] A "capture island" would include the equipment necessary to separate CO_2 from the plant's exhaust gas, remove impurities from it, and compress it for delivery to a pipeline.

[5] These changes could include replacement of the low-pressure section of the steam turbine and some changes to the existing boiler, both due to the need to supply large quantities of heat to the PCC island. By some estimates, 50 percent of the steam through the low-pressure turbine may need to be diverted to the PCC island. Changes to the cooling water system at the existing plant might also be required.

[6] The size of the main CO_2 absorber and regenerator vessels and the CO_2 compressors may be especially important in this regard.

In addition to the size of the PCC equipment itself, the extent to which CO_2 is removed from the full volume of the coal boiler exhaust is an important and somewhat independent parameter. A high level of CO_2 removal will have impacts on the plant's steam cycle and boiler operation that differ from those occurring with lower levels of removal or projects utilizing only a fraction of the exhaust gas ("slip streams"); in those cases, far less steam will be required, and other integration issues are also lesser.[7]

The electric generation industry is unlikely to consider adoption of PCC retrofits to coal power plants until there is enough commercial operating experience in a context similar to the investments they are considering to be confident that the project will be successful. Consequently, the development of PCC technology for retrofits must go through several stages in the pioneer phase:

- Several 50–250 MW projects will need to be built on slip streams of larger units to demonstrate core PCC technologies.

- Several larger (500 MW) projects with capture on the full exhaust of a large unit will need to be built to demonstrate integration of PCC with existing plant systems.

Pre-Combustion Capture from Surface Gasification

Pre-combustion carbon capture in gasification systems has been commercially available for decades. These systems are used to adjust the syngas composition in order to make fertilizer, fuels, or other industrial chemicals from gasified coal.

In pre-combustion capture, the synthesis gas composition is altered with a water-shift reaction to convert carbon monoxide into hydrogen and carbon dioxide. The carbon dioxide is removed from the synthesis gas in industrial gasification systems using commercially available processes such as Selexol™ or Rectisol.™

Because these technologies have been commercially available for so long, CO_2 capture in gasification systems face different technical uncertainties than post-combustion capture. These challenges include:

- *Integration uncertainties*: In a gasification system with pre-combustion CO_2 capture, several complex sub-systems must work harmoniously together for the full system to function properly. In particular, the gasifier, the CO_2 removal system, and the downstream turbine must be mated correctly over a range of operating conditions (e.g., partial load). Currently, there are around twenty integrated gasification combined-cycle (IGCC) plants worldwide, but only two of these capture significant quantities of CO_2 before the syngas is combusted in the turbine. These two

[7] Irrespective of the PCC train size, the percentage of CO_2 captured from a treated stream generally will be maximized, typically at 90 percent.

plants are found at Italian refineries that gasify refinery wastes, capture CO_2 (in order to produce hydrogen), vent the CO_2, and burn some of the remaining shifted syngas in combined-cycle turbines—operations that are similar to an IGCC system with capture.

- *Hydrogen turbine and systems integration uncertainties*: There are numerous uses of combustion turbines operating at high hydrogen fractions in a variety of industrial settings (e.g., refineries). A key technical variable for IGCC is the hydrogen fraction in the gas reaching the turbine. Conventional IGCC turbines can accept hydrogen fractions in syngas resulting in up to about 65 percent carbon capture. As much higher carbon capture levels (at least 90 percent) will be required to meet mid-century GHG emissions reduction targets, experience needs to be gained with hydrogen fractions in gas reaching combustion turbines at 65–90 percent carbon capture levels. *Therefore, the pioneer phase will need to develop projects that include a range of capture levels (50–90 percent) in order to gain greater experience with both integration and hydrogen levels in the turbines.*

Surface gasification has a key advantage for developing transport and EOR infrastructure: It can be built today, relatively quickly, and at larger scale than other CO_2-capture options. For example, Denbury's proposed Midwest pipeline would be one of the largest pipelines to take advantage of pre-combustion gasification advantages. It would connect existing EOR fields in Louisiana with proposed gasification plants in the Midwest (located where EOR is absent).

Surface gasification projects in the pioneer phase should include:

- Two 200 MW IGCC plants with 90 percent capture of CO_2
- Three 500 MW IGCC plants with 50–65 percent capture of CO_2
- Two 500 MW SNG-NGCC plants with 50 percent+ overall CO_2 reduction compared to conventional coal plants
- Two 500 MW equivalent plants for SNG with ~90 percent capture

Developing these plants would address both technical and cost uncertainties associated with gasification and pre-combustion capture.

Underground Coal Gasification

Underground Coal Gasification (UCG, also known as in-situ gasification) holds the potential to radically lower the cost of generating electricity using coal with CCS. UCG gasifies the coal in the coal seam (in situ), thus eliminating the investment in surface gasification equipment. It also potentially eliminates conventional mining practices. There have been several successful commercial

Diagram of Underground Coal

UCG pilots developed in Australia, China, and South Africa. Additional commercial-scale projects are under development based on those pilots, and other projects have been proposed in Alaska, Saskatchewan, and India.

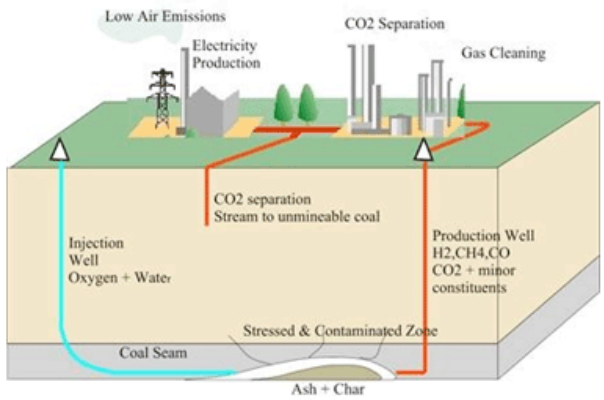
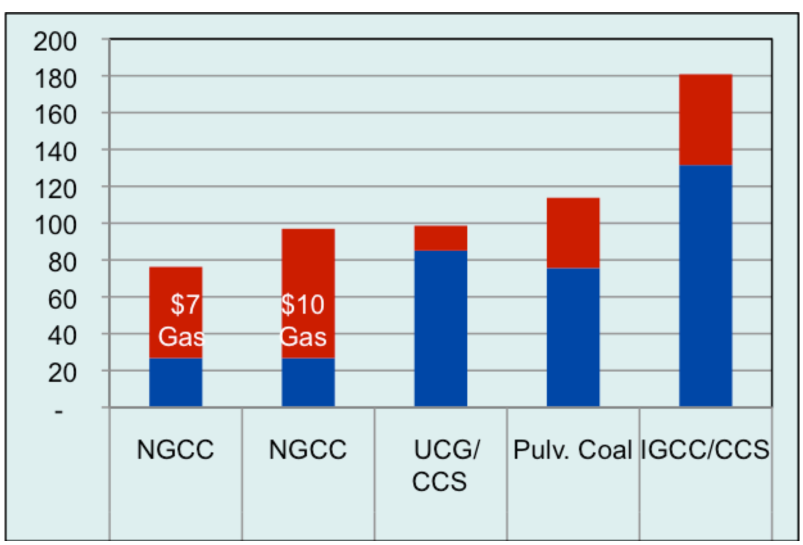


Diagram of Underground Coal Gasification

Early estimates of UCG costs ($/MWh) fall somewhere between those of natural gas generation and conventional coal plants—but UCG costs include 80 percent capture of CO_2, as opposed to zero capture for the gas and conventional coal plants. If this estimate holds true, *UCG could significantly reduce the cost of deploying CCS* in the power sector.

Electricity Costs ($/MWh) of Various Technology Options

Electricity Price, $/MWh



Technical uncertainties associated with UCG include:

- *Environmental performance*: In addition to the air standards that other power sources must meet, UCG has at least two other areas of concern: subsidence and groundwater protection.

  In the 1970s, '80s, and '90s, DOE and private firms conducted numerous pilot demonstrations of UCG. Most of these worked well. Those that were successful were located in deep coal seams that were far from drinking water. But some, which were located in shallow coal seams in or above drinking water, resulted in groundwater contamination. Since then, pilot projects in other parts of the world, including Australia and South Africa, have avoided these siting problems, but the public will demand that new UCG projects be fully monitored to ensure safe operation.

- *Scale*: Outside of the former Soviet Union, most UCG projects have been conducted on a fairly small scale. Building more 200 MW (and larger) facilities would provide valuable opportunities to address technical issues involved in scaling up the technology.

- *Utilization*: There is no experience using UCG-derived syngas in combustion turbines (except perhaps for limited tests in the former Soviet Union), and experience using that gas in other internal combustion engines is quite limited. The first projects to use turbines with UCG gas will require special technical attention and support.

- *CO_2 capture*: Adding CO_2 capture to UCG operations would raise issues similar to those involving surface gasification plants. UCG syngas can be more variable in composition, creating additional technical complexity.

CATF recommends building three UCG plants in the pioneer phase to provide the operating experience necessary to address technical and cost issues that are critical to evaluating UCG's potential for wider application.

Post-Combustion Capture on Natural Gas Combined-Cycle Plants

Several vendors offer post-combustion capture systems for NGCC plants. For example, Fluor Corporation's Econamine amine PCC system captured 365 tpd of CO_2 from the exhaust of a natural gas-fired combustion turbine in Bellingham, Massachusetts, from 1991 to 2005. Fluor's system is licensed for dozens of small commercial projects around the world. Mitsubishi Heavy Industries and Kansai Electric Power have developed a CO_2 removal technology known as KM-CDR based on a specially formulated amine solvent. The technology has recently been used on the exhaust steams of natural gas processes at up to 450 tpd in several facilities.

To address remaining technical and economic issues, at least one 100 MW post-combustion capture NGCC project should be completed. The scale of this demonstration project does not need to be as large as that for a coal power plant, since the majority of the electricity produced in an NGCC is in the combustion turbine, and the steam system (where the PCC will derive its energy) is significantly smaller.

Saline Formation Sequestration

Oil and gas companies have been injecting CO_2 underground to stimulate additional oil production since the mid-1970s. Over 60 million tons of CO_2 is injected for enhanced oil recovery (EOR) every year.

But commercial scale injection of CO_2 in saline formations is limited to a few million-tons-per-year projects across the world. Yet these deep brine or saline formations have great capacity for sequestration. These areas are composed of porous rock that contains brackish water with naturally high salt and contaminant levels. Sites for geologic carbon sequestration can be located on land or offshore.

The Intergovernmental Panel on Climate Change has estimated there is sufficient global geologic capacity to sequester 10,000 billion tons of CO_2. Department of Energy estimates for CO_2 sequestration capacity are shown below.

Formation Type	Billion Metric Tons of CO_2 Sequestration
Saline Formations	919–3378
Oil and Gas Formations	8.24
Unmineable Coal Beds	156.1–183.5

The U.S. power sector currently emits 2.4 billion metric tons of CO_2 annually.

To move saline sequestration to the commercial stage, investors will need to see several large-scale saline sequestration sites developed during the pioneer phase. These projects should provide valuable experience dealing with critical issues with this technology such as:

- *Scale*: The largest saline formation injection sites in the world average 1 million tons of CO_2 injection per year. A large coal plant, in contrast, emits around 6 million tons of CO_2 per year. Developing saline injection sites at this scale is important.

- *Site selection, characterization, and monitoring protocols*: The tools needed for the development and operation of saline sequestration have been used in EOR and other sub-surface commercial activities, but they have not been fit-to-purpose for this specific use except in some early demonstration projects.

- *Experience*: While industry experience provides a solid foundation of knowledge in this field, we still lack essential institutional and professional expertise in dealing with the long-term geophysics, geochemistry, and geomechanics of saline sequestration.

There are also non-technical issues that introduce additional uncertainties for initial development of saline sequestration projects, such property rights, pore-space, and permitting.

To overcome these barriers, CATF recommends developing five saline storage sites using existing high-purity CO_2 streams. These projects should operate for five years and inject around 5 million tons of CO_2 per year.

Infrastructure Barriers to Pioneer CCS Projects

A key barrier to developing early CCS technology is the lack of infrastructure. The existing CO_2 pipeline network is largely focused on EOR (and often on delivering natural sources of CO_2 to EOR fields). Pipelines do not connect the eastern United States, where most domestic coal is consumed, with existing EOR fields. Saline formations, which are abundant in the Midwest, have not been developed for use by potential CCS projects. This has created a chicken-egg dilemma: Developers who want to capture CO_2 cannot obtain financing because there is no place to store the CO_2—and sequestration sites cannot be built because capture is not occurring. To address this situation, the pioneer phase needs to undertake several initiatives:

- *Pipelines to connect with enhanced oil recovery fields:* EOR can be an important first wedge in the development of CCS. Access to EOR sites can greatly reduce the complexity of project development. However, a sufficiently reliable supply of CO_2 is necessary before developers will build pipelines to EOR fields. At least one CO_2 pipeline is needed to connect the Midwest and existing EOR fields. The Denbury Pipeline is furthest along in planning. The feasibility study for this project can be found at Denbury's website: http://www.denbury.com/index.php?id=53

- *Characterizing ten to twenty saline storage sites*: Characterizing sites is a key first step in developing saline storage site infrastructure. From this group of ten to twenty sites, perhaps only a handful will ultimately be fully permitted and operated as commercial facilities

- *Offshore saline storage sites:* Substantial sequestration resources reside in state and federal waters offshore, currently managed by the Minerals Management Service, potentially representing the opportunity to sequester several trillion tons of CO_2. Offshore resources have several distinct advantages compared to onshore resources, including clear ownership of pore volumes (state and federal), ease of monitoring (time-lapse seismic), a streamlined regulatory environment, and limited land-use conflicts in areas where CO_2 pipelines would be built. Most of this resource lies along the East Coast and the Gulf of Mexico. In some cases (e.g., North Carolina and New Jersey) the offshore resources may provide the only potential reservoirs available for sequestration of CO_2 from large point sources (power plants, refineries, chemical plants). Enough data exist to make credible early assessments of resource quality, density, and likely effectiveness. Improved estimates of good CCS resource location and capacity could be developed by DOE or the Department of the Interior for a modest cost ($10 million over three years). This would greatly improve our understanding of offshore resources, facilitating planning of changes to the power sector and major infrastructure investments.

Barriers in the Cost Reduction Phase

Initial CCS efforts must evolve from a handful of projects to a full CCS industry. As used here, an "industry" means a strong *density* of commercial activity up and down the CCS supply chain. For example, as the industry emerges, new companies will form and existing companies will expand to provide equipment and services for capture, storage, and transportation of CO_2. As a result, new technologies will evolve and costs fall. New and expanded institutions in federal, state, and local governments will facilitate industry expansion. While these elements may begin to emerge in the pioneer phase, they are unlikely to develop fully until the cost reduction phase.

The barriers to CCS are likely to evolve as the scope of CCS grows beyond the pioneer phase. Technology barriers will diminish, and economic barriers will become the main obstacle in the cost reduction phase.

In order to understand the economic policy needs during the cost reduction and mature industry phases, CATF commissioned the Northbridge Group to model the U.S. coal fleet. Northbridge analyzed the economics of retrofitting the coal fleet in the eastern interconnection and ERCOT (89 percent of U.S. coal capacity) on a unit-by-unit basis and compared those results to the economics of continuing to operate the units without CCS or retiring them. The modeling examined a variety of carbon prices and incentives (see the appendix for modeling details). The modeling results surprised us. We found:

1. *Uncontrolled natural gas combined-cycle plants are economically attractive compared to installing CCS on coal plants*. Uncontrolled natural gas plants are right now relatively cheap, and replacing uncontrolled coal plants with natural gas combined-cycle plants results in about a 50 percent reduction in CO_2. *But this reduction is only a half step compared to mid-century CO_2 reduction needs*—and would create a new fleet of *uncontrolled, grandfathered natural gas power plants*. Several factors combine to favor half steps over CCS full steps: 1) the trajectory of CO_2 reductions favored by bills in Congress; 2) the old age of the U.S. coal fleet; 3) the projected abundance and potentially low natural gas prices in the next decade or more due to shale gas; and 4) rising construction costs that favor less capital-intensive combined-cycle plants. *This finding underscores the need for plant performance standards for CO_2 emissions, particularly for natural gas plants, that in effect require the installation and operation of CCS. Minimum performance standards must be*

included in any legislation, in addition to caps on CO_2 emissions. Alternatively, in the absence of legislation, performance standards for new and existing units must be promulgated under current Clean Air Act authority, in order to avoid construction of a new generation of CO_2-emitting power plants.

2. *Carbon prices alone will not drive significant CCS deployment before 2040*. If the only mechanism for addressing climate change were steadily increasing carbon prices at levels contemplated by Congress, CCS would not deploy to any significant degree before 2040. Reductions would come from fuel-switching to natural gas, but this action alone would leave the country unable to meet deep emissions reduction goals by 2050. *This finding underscores the need for significant additional incentives to drive CCS deployment over the next thirty years.*

3. *In order to spur CCS deployment, a carbon cap must fund CCS incentives*. Budget deficit concerns will likely require new revenue sources to offset future federal CCS incentives. Carbon caps do raise this revenue, and most climate bills return some of that money to CCS incentives. A carbon tax or wires charge can also play a similar role.

4. ***How** CCS incentives are distributed matters as much as **how much** incentive money is available for CCS*. Our models show that the method of distributing CCS money determines how much CCS actually gets deployed. The distribution method favored by some utilities—a fixed, high price per ton of carbon dioxide—spends through available funds before CCS is deployed at levels sufficient to move through learning curves and bring technology costs down. In contrast, a reverse auction where incentives are bid (and lowest bidder wins) allows significantly more CCS to be deployed, enough to complete learning and reduce costs.

5. *$275 billion in federal support is needed to develop 50 GW of CCS in the cost reduction phase*. The basis for this cost estimate is detailed in the NorthBridge Modeling Results appendix to this report.

Pioneer Phase Recommendations

In his February 3, 2010, memorandum, the president outlined a goal of building five to ten coal-with-CCS projects by 2016. CATF believes that this goal is an important first step toward fulfilling broader objectives of the pioneer project phase of coal with CCS. But CATF's analysis suggests that eliminating the major technical risks in the pioneer phase requires at least *thirty* projects; five or ten will not be enough, as the analysis presented in the previous chapter demonstrates. Furthermore, existing federal incentives are insufficient for the needed projects. Our recommendations here focus on three areas of activity that would make the pioneer phase of CCS successful: 1) identifying the right projects to complete; 2) better utilizing existing incentives and authority; and 3) providing additional funding for CCS.

CATF's recommendations are organized below in groups of items that require action by specific actors—the president, Congress, and executive branch agencies.

A Comprehensive CCS Project Portfolio

Recommendation 1: *The Obama administration should pursue the following 2018 project portfolio*:

- Commercialize 4 GW of post-combustion capture to full scale by building at least the following range of PCC units:
    - Five 50–250 MWe projects integrated at plant scale on slip streams of larger units
    - Seven 300–1,000 MWe projects with capture on the full exhaust of a large unit
- Develop at least one 100 MW post-combustion capture project on a large natural gas combined-cycle plant.
- Build three commercial-scale underground coal gasification plants with CCS.
- Expand regional CO_2 pipeline networks, especially those that link regions to existing EOR fields.
- Build nine commercial-scale IGCC plants with CCS, SNG with CCS, and other gasification with CCS, including:
    - Two 200 MW IGCC plants with 90 percent capture
    - Three 500 MW IGCC plants with 50–65 percent capture

- Two 500 MW SNG-NGCC plants with 50 percent+ overall carbon dioxide reduction compared to conventional coal plants
- Two 500 MW equivalent SNG plants with ~90 percent capture

- Develop five large-scale commercial saline sequestration projects as soon as possible.

CATF urges DOE to look for synergies between projects. For example, Denbury's Midwest CO_2 pipeline is a key priority. To be built, however, the project needs several gasification projects to break ground. DOE could achieve multiple objectives by prioritizing funding for the gasification projects linked to Midwest Pipeline.

Using Existing Executive Authority

The Obama administration can take actions that would allow many projects to begin or expand operations. In some cases, congressional action will also be needed.

Recommendation 2: *DOE should use $1 billion in stimulus money to fund a 65 percent capture CCS project at the Edwardsport IGCC plant in Indiana*. This 630 MW project is already under construction and is actively pursuing carbon capture and storage:

- *Speed*: The project is 50 percent constructed. This may be one of the fastest ways to reach a large, commercial-scale coal CCS in the United States.
- *Scale*: The project is at commercial scale. Its size (630 MW) means that the CCS plant would be easier to replicate by other utilities.
- *Quantity*: 65 percent capture from a 630 MW plant would help establish commercial CCS.
- *Rate base*: The plant has already received approval from Indiana regulators to be placed into the rate base of Duke's customers.

DOE funding on this project would lead to one of the largest and fastest coal projects with CCS in the world.

Recommendation 3: *President Obama should direct the U.S. EPA Administrator to include, in Clean Air Act guidance due out by January 2011, regulatory incentives[8] for BACT standards for new and modified major sources,*

[8] There is an existing regulatory element that provides a temporal waiver from the BACT requirements for implementing "innovative control

based on the deployment of CCS technologies, in cases where there is potential for at least partial emissions control through deployment of CCS. EPA should also be directed to change the innovative technology waiver (currently available through the PSD permitting process) to make it more attractive to project proponents who want to use innovative technologies such as CCS that can make stepwise improvements in the ability to reduce CO_2 and other GHGs at major new and modified stationary sources.

Without a near-term regulatory incentive (for example, allowing a graduated phase-in to BACT emissions limits at plants that are first movers for CCS), owners and operators of new or modified sources will not have the flexibility to deploy CCS or other technologies that offer the promise of deep reductions in GHGs. Without such guidance from the agency, deep emissions reductions are not guaranteed from major new and modified stationary sources, and these technologies will not move into the market in the near term.

Recommendation 4: *The president should direct the Department of Energy (and/or other federal agencies) to purchase electricity generated by FutureGen.* Purchasing the electrical output would allow the project to operate for not just five years (as described in some plans), but for twenty years or more. The total value to FutureGen over the two decades of this purchase arrangement might be as much as $2 billion–$4 billion. This support, coupled with a loan guarantee, might allow this long-delayed project to finally break ground. DOE already has purchasing requirements for renewable energy, so adding CCS from FutureGen would not be unprecedented. Also, DOE has suggested that the capture rate at FutureGen might be reduced from 90 percent to only 65 percent. DOE should ensure the project attains 90 percent CCS as soon as possible by purchasing the plant's electricity, which would provide the financial certainty necessary to achieve that goal.

Recommendation 5: *The secretary of energy should use his authority to waive the 50 percent cost-share requirements for pioneer post-combustion capture projects.* Given the unique circumstances for PCC plants in the pioneer phase, federal support must pay *almost all* of the cost of the demonstration projects. CATF estimates it would cost *$10 billion (2010 dollars) to build 4 GW of PCC CCS by 2018.* This would require funding for:

- *Capital costs:* CCPI-like grants to cover 80 percent of the added capital costs

- *Operating costs:* Direct payments for CO_2 sequestered that also pay for CCS operating costs, and the 20 percent of capital not covered by a CCPI-like grant

---

technologies." It is referred to commonly as a regulatory incentive to promote the use of such technologies.

Recommendation 6: *DOE and the Internal Revenue Service (IRS) should work together to ensure that CCS projects are eligible for multiple tax credits*. For example, while federal law does not prohibit projects from obtaining both 48A and 45Q incentives, IRS has the discretion to force projects to choose one or the other. Realistically, however, CCS projects cannot be economically viable without the support of multiple incentives. The IRS should clarify its policy on these questions to provide greater support for these vital projects.

Recommendation 7: *The Obama administration and Congress should support increased cooperation between the EPA's air and water offices, and the cultivation of additional in-house experience with CO_2 sequestration* technologies, geologic formations and resources, and permitting, in consultation with DOE's National Energy Technology Laboratory (NETL) and the U.S. Geological Survey. EPA needs funding and authorization to create and staff a new division within the agency dedicated to CO_2 sequestration and all related permitting issues.

Congressional Action

Recommendation 8: *The Obama administration and Congress should provide additional incentives for pioneer phase CCS projects*. As noted earlier, most of the financial support for existing CCS projects is coming from state programs. The roughly $8 billion in federal support is important, but current federal and state support is insufficient to complete the number of pioneer phase CCS projects the nation needs. An additional $20 billion in funding is needed to achieve our policy objectives with CCS. There are several ways of potentially providing those funds; three ideas are outlined below, but they are meant to be illustrative examples, not a comprehensive list:

> **1**. *Congress could establish a wires charge to fund $20 billion worth of pioneer CCS projects*. The revenues would be used by DOE to fund grants for additional projects needed to complete the pioneer phase of CCS. The DOE awards would cover the difference in cost between the CCS project and the most economically competitive alternative, an uncontrolled natural gas combined-cycle power plant.
>
> This proposal is a modification in several fundamental ways to the wires charges found in the Boucher bill, Waxman-Markey, and Rockefeller-Voinovich:
>
> - The amount of revenue raised would be much higher than current wires-charge proposals contemplate.
> - The wires charge would not require a thirty-state opt-in provision before taking effect; Congress would establish it.

- DOE would control and distribute the funds, selecting projects that complete the portfolio of CCS projects needed to ensure technical risk barriers to CCS are removed.

This model is similar to the rate-base decision taken by states, where a particular project is funded by a larger (regional or statewide) customer base. In this case, the marginal cost of the pioneer phase projects would be supported by the national rate base. This approach would not affect electricity rates significantly, while providing the funds needed to efficiently complete the pioneer phase. Projects would no longer need to piece together a complete funding package from a mixture of federal and state programs.

2. *Expand the clean energy standards contemplated in various energy bills to include purchase of electricity from CCS projects*. To be effective, the clean energy standard must specify required levels of CCS-based electricity by an early date. Otherwise, the standard may not drive CCS at levels needed to complete the pioneer phase quickly enough. A clean energy standard that sets a strong requirement for CCS power in later years could drive the higher levels of CCS needed (50 GW) to complete the cost reduction phase.

3. *Congress could pass a package of incentives that collectively could complete the pioneer phase*. The menu of options would include:

- *Loan guarantees*: Increase the loan guarantees available for projects using CCS. This has the advantage of requiring relatively small federal expenditures. For example, a $2 billion loan guarantee might only cost the federal government hundreds of millions of dollars, while providing vital support for the project. Congress should also consider streamlining the EIS process, which currently takes several years to complete.

- *Create a production tax credit for SNG*: Many CCS proposals involve gasifying coal or petcoke to make methane, also known as "substitute natural gas," or SNG. A variable tax credit for production of SNG made from gasification of a solid feedstock should require projects to store or beneficially use 90 percent of the CO_2. The tax credit could be capped at $1 billion–$2 billion.

- *CO_2 sequestration credit*: The Emergency Economic Stimulus Stabilization Act of 2008, section 115, created a CO_2 sequestration credit. This credit could be expanded to at least $5 billion over 10 years and include:

    - New funding "pools" for power-only, industrial, and high-purity existing CO_2 streams (which will drive saline site development)

    - Provision for projects to reserve credits (which facilitates financing)

    - Raised cap on tons stored and price per ton of CO_2 used for both EOR and saline sequestration

- *Accelerated depreciation*: Allowing faster depreciation of equipment and plants that include CCS would make projects more economical.

- *Increased CCPI funding*: Additional Clean Coal Power Initiative funding would help close the funding gap that pioneer projects face.

Recommendation 9: *Provide $350 million in federal funding to characterize ten to twenty saline sequestration sites in 2011–2012*. There is no economic incentive to develop saline sequestration in advance of a carbon price. Even then, a low price would favor EOR in early projects over saline formations. This program would develop sequestration-ready sites by funding the full characterization and permitting costs. The funding would:

- Be limited to $30 million per project

- Require a minimum 5 percent cost share

- Focus at least 75 percent of funds on saline formations because most depleted oil and gas sites are already well-characterized for sequestration purposes.

Recommendation 10: *Provide $10 million for an assessment of offshore geologic storage potential*. The departments of Energy and Interior should collaborate to develop credible, timely assessments of U.S. offshore carbon storage capacity, specifically focusing on resource quality, density, and likely effectiveness.

Cost Reduction Phase Recommendations

The cost reduction phase of the CCS industry should involve a large expansion in the number of CCS projects in the United States, perhaps creating 50 GW or more of additional CCS power. This expansion is expected to drive down costs as the industry moves up the learning curve, builds the initial pipeline and CO_2 injection site infrastructure, and creates new engineering and manufacturing knowledge. New public and private institutions are also expected to emerge to facilitate industry growth.

This chapter is organized in several parts:

- CCS industry characteristics in the cost reduction phase. This section describes how costs fall as a result of wider CCS deployment, how infrastructure is expected to expand, and how the creation of a geologic storage utility could help CCS growth in this phase.

- Policy options that drive CCS deployment in the cost reduction phase. This section describes the following federal policies needed to significantly expand the domestic CCS industry:

  1. *CCS financial incentives* structured through a reverse auction and allocated in sufficient quantity to drive sufficient CCS deployment to capture significant cost reductions and expand core CCS infrastructure

  2. *Carbon emissions constraints* to provide a foundation for the subsequent mature industry phase. The emphasis of this analysis is on GHG emissions performance standards for new and existing fossil power plants.

- Recommendations for the Interagency Carbon Capture and Storage Task Force. These recommendations address funding levels and mechanisms needed to ensure wide-scale CCS deployment in the cost reduction phase.

Characteristics of the CCS Industry in the Cost Reduction Phase

In this phase, CCS would be expected to develop on a wide scale, following successful technical demonstrations in the pioneer phase. Costs are expected to fall as more experience is gained with CCS designs, construction, and operations. Infrastructure such as CO_2 pipelines and injection sites would expand, and new public and private institutions would emerge to facilitate CCS growth.

Cost Reduction Through Deployment

Early deployment of CCS technology after the pioneer phase can significantly lower costs and improve operating efficiency if sufficient technology[9] is deployed. Analyses of historical development of similar technologies and expert opinion suggest that substantial cost reductions and operating improvements are likely to be realized through worldwide development of about 100 GWs of CCS capacity.[10] Assuming that half of development occurs outside of the United States, about 50 GW of CCS will need to be developed domestically.

These studies assessed energy technology improvements observed over many decades, including generating technologies such as pulverized coal and natural gas combined cycle, as well as emissions control technologies such as flue gas desulfurization and selective catalytic reduction. These studies suggest that, when applied to conventional coal plants, *the capital costs of carbon capture could decline by about 15 percent*, and *the overall cost of capture systems* (including capital, O&M, and the impact on the host coal generator) *is likely to decline by about 25 percent* when 100 GWs of CCS capacity are deployed worldwide.

CCS Infrastructure

Deployment of 50 GW of domestic CCS projects will also support the development of the infrastructure necessary to create a national industry by

- Driving the creation of at least 5,000 miles of new CO_2 pipeline

- Substantially growing domestic enhanced oil and gas recovery projects, potentially expanding domestic recoverable oil reserves in the lower forty-eight states by more than 200 percent

- Providing enough CO_2 to develop saline geologic formation CO_2 injection fields in major midwestern, southeastern, and Interior West geologic basins.

[9] Conventional aboveground IGCC/CCS, advanced gasification technology IGCC/CCS, underground coal gasification IGCC/CCS, gas combined-cycle power with CCS, and retrofit of coal units with post-combustion capture.
[10] See, for example, IEA Greenhouse Gas R&D Programme (IEA GHG). 2006. "Estimating Future Trends in the Cost of CO2 Capture Technologies." Report no. 2006/5. January; Edward Rubin, Chao Chen, and Anand Rao. 2007. "Cost and Performance of Fossil Fuel Power Plants with CO2 Capture and Storage." *Energy Policy* 35:4444–54; and Sonia Yeh and Edward Rubin. 2007. "A Centurial History of Technological Change and Learning Curves for Pulverized Coal-Fired Utility Boilers." *Energy* 32:1996–2005.

Policy Options to Drive CCS Development in the Cost Reduction Phase

Policy options to drive emissions reductions in the cost reduction phase include carbon caps, carbon taxes, financial incentives, and GHG performance standards. CATF has studied a range of policy scenarios for power-sector GHG emissions through 2050. This analysis included evaluations of plausible carbon caps, CCS financial incentives, and power generation GHG emissions performance standards.

The analyses revealed several important conclusions:

- Plausible *carbon caps alone can drive coal fleet retirement and its replacement with natural gas power* (without CCS) by 2040. But this would reduce the power sector's GHG carbon emissions by only 50 percent, leaving significant GHG emissions from natural gas power generation that would need to be reduced relatively quickly to achieve plausible mid-century targets of 80–90 percent reduction in power-sector GHG emissions from today's levels.

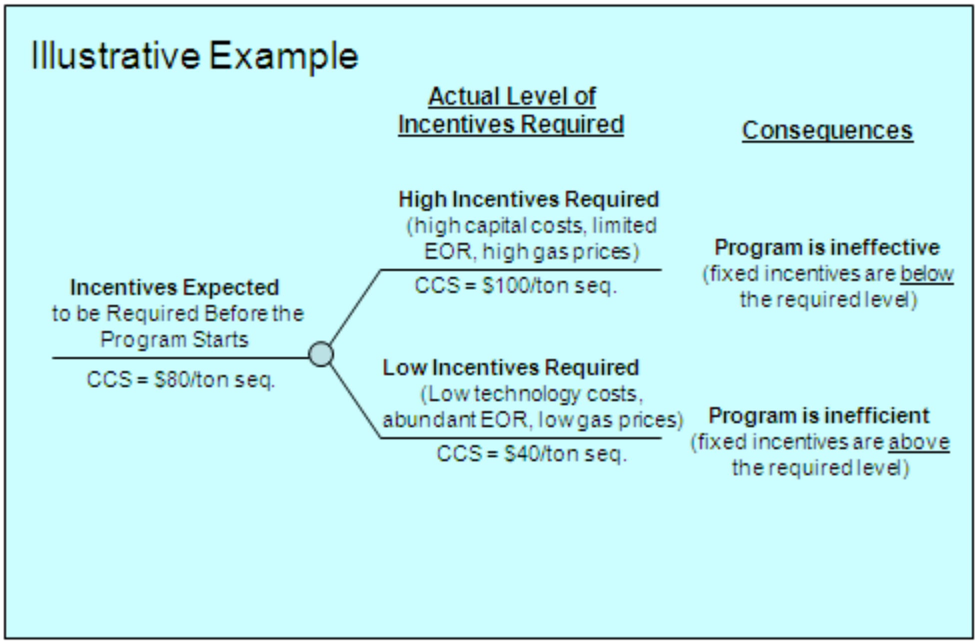
- *Significant CCS financial incentives can drive deep reductions in power-sector GHG emissions by sequestering up to 90 percent of the carbon emissions from the coal fleet*, which is the largest source of carbon emissions in the power sector. Such incentives would require an estimated \$5 billion–\$46 billion (in 2010 dollars) in funding to support 50 GW of CCS capacity (with the price depending upon assumptions about carbon prices).

- *GHG performance standards alone can also drive deep GHG emissions reductions*. But they must be applied to all electric generators, including those using natural gas, in order to achieve 80–90 percent mid-century power-sector emissions targets. *GHG performance standards will not, by themselves, drive early commercialization of CCS technology* (in the same way that a carbon cap by itself will not drive early CCS commercialization).

To drive cost reduction phase CCS expansion and to establish a foundation for achieving deep power-sector GHG emissions reductions by mid-century, some combination of financial incentives and emissions performance standards will be needed. These ideas are discussed in detail below.

Financial Incentives Structure: Reverse Auction

How incentives are distributed matters as much as the scope of the support. Effective financial incentive design is critical to ensure CCS projects receive sufficient funding to make them economical in changing market conditions, while not overcompensating project developers. One mechanism to achieve this result is to distribute incentives through a ***reverse auction***, also known as a procurement auction. This is a type of auction that involves a buyer purchasing a product or service, with sellers competing by offering bids for the contract to provide the product or service, with the low bid winning the auction. Reverse auctions were pioneered twenty years ago by automotive and aerospace buyers, and they are often used today for defense procurement and providers of default electricity service in competitive electricity markets.[11]

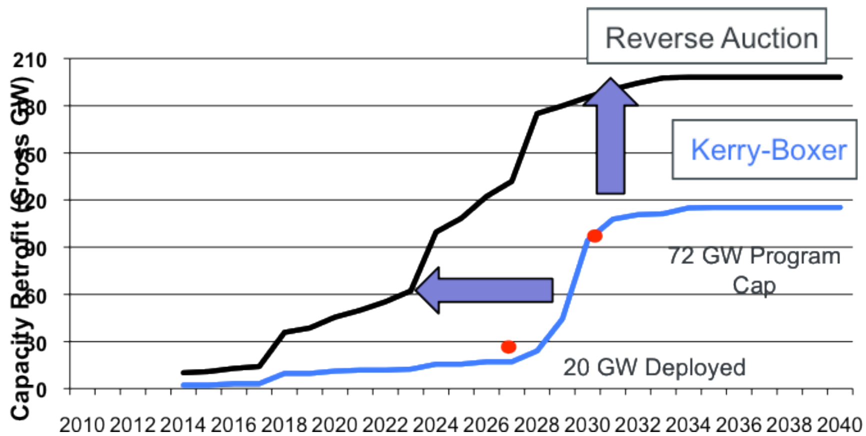


In the CCS context, the government would use reverse auctions to procure sequestration of CO_2 captured from fossil generating units. Plant owners and equipment vendors would compete against one another by reducing the price they would share for the sequestration.

The figure shown above illustrates the range of uncertainty in the level of incentives required to deploy CCS technology. As shown, if a fixed incentive is used, it will almost always be too low (in which case the technology will not be deployed) or too high (in which case developers will be over-compensated). In contrast, a reverse auction process would allow the incentive price to fluctuate based on technological and market conditions, helping to ensure the program will be both effective and cost-efficient.

[11] See http://www.catf.us/resources/publications/files/Using_Reverse_Auctions_in_a_CCS_Deployment_Program.pdf

Fixed Price Credit versus Full Reverse Auction for CCS Deployment Incentives in Kerry-Boxer Bill



Among other benefits, the reverse auction process would help ensure that the deployment program minimized the amount of incentive funding needed to sequester CO_2 from 50 GW of CCS capacity. As an example, if the reverse auction program in the proposed Kerry-Boxer bill were applied to the entire CCS deployment program proposed in that bill, it would double estimated CCS deployment, as shown in the figure above.

Performance Standards, Carbon Caps, and Carbon Pricing

In theory, GHG emissions caps combined with CCS financial incentives could potentially drive power-sector GHG emissions nearly to zero, while ensuring that fossil-fueled systems remain a viable power generation option. Establishing GHG emissions ***performance standards*** for both new and existing fossil power generation—combined with financial incentives for CCS—could also achieve the same objectives. EPA has the legal authority to establish such standards for large point sources under the Clean Air Act.

GHG performance standards have several potentially important attributes:

- Performance standards for new generation would send *a more effective and certain price signal* to zero-carbon power generation technology developers than is possible with emissions trading, which have suffered from high price volatility and GHG allowance price forecasting challenges when applied on a large scale (for example, the EU ETS).

- GHG performance standards can provide more certainty about the timing and depth of future power-sector GHG emissions reductions.

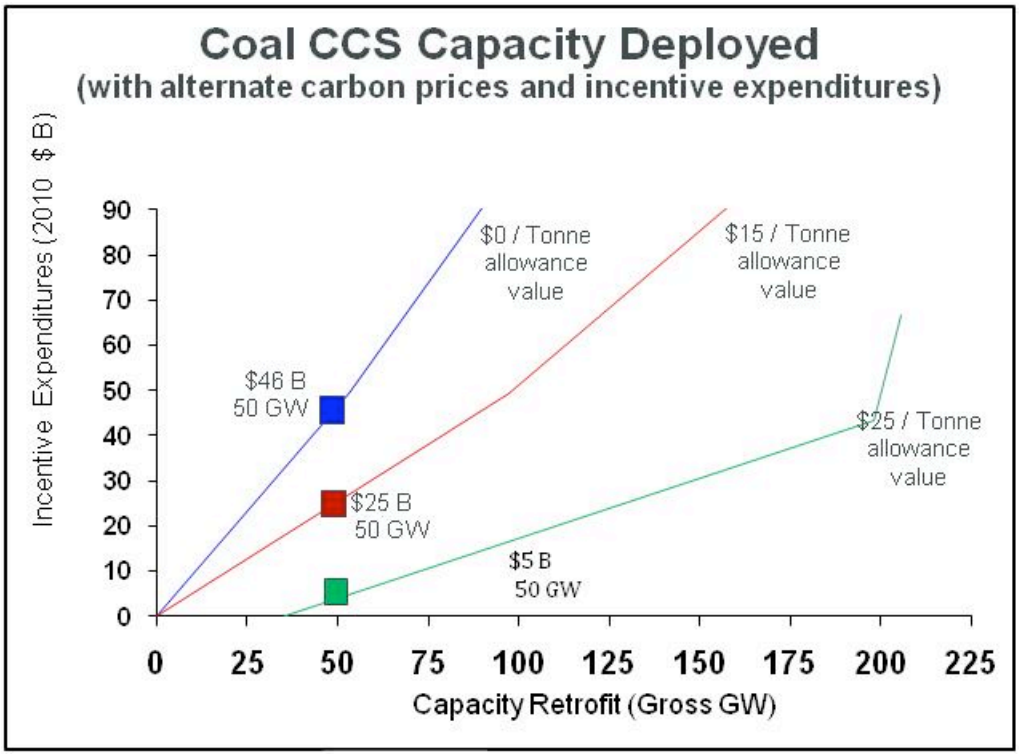
- GHG performance standards can be implemented through simple legislative or regulatory mechanisms.

However:

- Performance standards alone will not raise funds that could be allocated to offset price impacts or to fund other climate objectives such as CCS technology development. To do so, performance standards would need to be combined with another source of revenue such as carbon pricing.

- An optimal policy may require a combination of caps, incentives, and performance standards. Incentives could be funded with revenue raised by the cap, while providing greater certainty through performance standards.

Notably, the amount of financial incentives needed to expand CCS is a function of carbon prices. For example, absent a carbon price, about $275 billion (shown in the chart below as a $46 billion 2010 dollar net-present-value figure) of financial incentives over several decades would be needed to drive development of 50 GW of CCS. In contrast, with a carbon allowance price beginning at $15/ton and escalating at 7 percent per year, the figure below shows that only about $165 billion (shown in the figure below as a $25 billion 2010$ NPV figure) of incentives would be needed to move 50 GW of CCS. When the carbon price increases to $25 per ton in 2014 (escalating at 7 percent per year), the incentive drops further, to about $12 billion (shown below as a $5 billion 2010$ NPV figure) at $25/ton.



(Figures assume distribution is occurring through a reverse auction, and that projects only receive enough funds to make them economical.)

In addition to lowering the amount of incentives needed for CCS, carbon prices provide one other potential benefit. Carbon pricing through a GHG emissions cap-and-trade system creates carbon allowances value that can provide a potential source of revenue for incentives.

Establishing and Achieving GHG Emissions Performance Standards

Establishing GHG emissions performance standards at levels reflecting the requirement to deploy CCS for new and existing fossil power generation (coal and gas) would provide certainty about future power-sector GHG emissions, and would build a foundation for the mature industry phase of deployment. This is true whether the performance standards are established in a new legislative enactment or under section 111 of the current Clean Air Act.[12] GHG performance standards would provide a clear signal to technology suppliers and EPC contractors that a sufficiently large CCS market will emerge to warrant investment in innovation and cost reduction (as opposed to approaching a project as a "one-off," in which all the extra costs included with such an approach are billed to that project).

Furthermore, these performance standards cannot be limited to coal-fired plants if we are to achieve the reductions we need from this sector of the economy, or move CCS into the mainstream. As described later, performance standards on

[12] 42 U.S.C. §§ 7411(b) & 7411(d).

new and existing gas-fired units would ensure that deep emissions reductions in the power sector are achieved by about 2050.

The administration needs to work on setting performance standards now for all new and existing coal- and gas-fired units (including those that co-fire biomass), even in the absence of legislative change. This will give clear information about the extent of the full suite of regulatory measures the industry should anticipate, providing industry with critical guidance as it makes retrofit/replace decisions for its older facilities.

We recommend that, if Congress has not passed legislation by January 2011 establishing specific GHG performance standards (whether or not accompanied by emissions caps), *EPA should be prepared to propose performance standards for new and existing coal- and gas-fired electricity generating units in spring 2011*. We also recommend that the administrator continue her policy, expressed in the tailoring rule, that biomass-related CO_2 emissions not be exempted from the accounting in the absence of further clarity on what constitutes sustainable biomass (as clean fuel) for co-firing.

At the outset, performance standards for new coal plants can be met with commercially available technology that has not yet been fully integrated in single projects, which will occur in the pioneer phase. Worldwide, several projects are demonstrating the various technology elements that would need to be integrated in the pioneer phase. For example, the Dakota Gasification plant in Beulah, North Dakota, is making substitute natural gas (SNG) through coal gasification and sequestering the captured CO_2 in the Weyburn oil fields of Saskatchewan, Canada. If the SNG produced here (or at other SNG plants with CCS) were used to produce power, the coal feed stock would effectively be providing power while sequestering about half of its carbon. Other examples under construction include China's GreenGen IGCC project (which will begin with limited CO_2 capture and expand in subsequent development phases to 90 percent capture) and Duke Energy's Edwardsport, Indiana, IGCC project (which is proposing to include limited CCS).

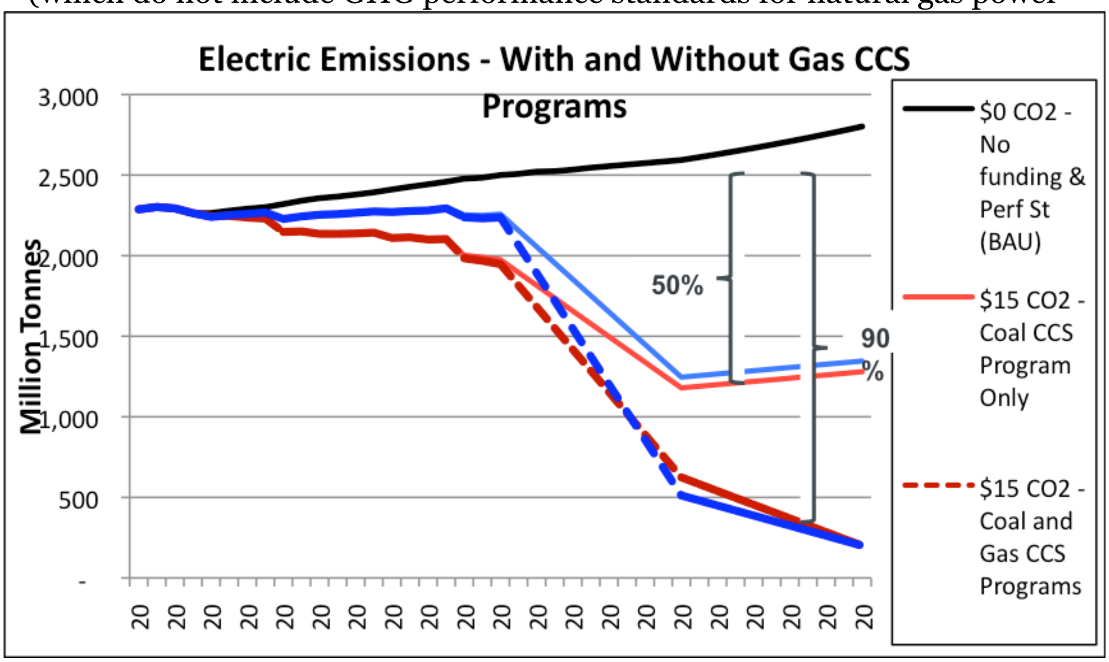
Performance standards for new gas plants can also be met with commercially available technologies. Major technology vendors are expected to offer performance guarantees for applying their post-combustion carbon capture technologies to natural gas power plants. Performance standards on existing coal plants can be implemented once the pioneer phase of CCS is complete, since it should include sufficient commercial-scale PCC deployment to commercialize this technology.

Best Available Control Technologies (BACT) in Permitting New and Modified Major Sources of CO_2. Additionally, as part of the EPA Assistant Administrator's Greenhouse Gas BACT Working Group, CATF recommends that the agency provide direction (through the guidance it intends to issue by January 2011) about the reliance on innovative control technologies, such as CCS, in setting emissions limits for CO_2 in the state and federal permits that will be issued in 2011.

Specifically, the innovative control technology waiver provisions in the Prevention of Significant Deterioration (PSD) provisions of the Clean Air Act can be revised to allow proposed new and modified facilities to deploy technology over a period of years, and through a range of BACT limits that must be met (at the latest) seven years after permit issuance or four years after the start of operations. Those waivers are rarely used because the EPA administrator's policy is they may only be used once for each technology. But the administrator has discretion to allow more extensive use of the waiver if it is deemed necessary to demonstrate the technology's performance. This flexibility is critical to encourage the use of technologies such as CCS that are complex and moving to market, and which offer the potential for substantial reductions in CO_2 emissions beyond what would otherwise be achieved in a BACT determination.

Why include natural gas?

The NorthBridge Group's analysis demonstrated that current policy proposals (which do not include GHG performance standards for natural gas power



generation) leave substantial power-sector GHG emissions after 2040 from uncontrolled natural gas power production, thus only getting slightly more than halfway to an 80 percent GHG emissions reduction target by 2050, as shown in the figure above.

Geologic Sequestration Utility (GSU)

A new institution is needed to support planning, deployment, and rate recovery of sequestration injections sites during the growth of CCS. A geologic sequestration utility would be a specialized, regulated utility that would commercialize injection (and, in some cases, transport) of carbon dioxide into brine aquifers. It would manage, and assume liability for, CO_2 disposal from power plants, manufacturers, and other stationary sources of CO_2.

For these services, the utility would recover its cost in rates, along with a reasonable rate of return. Its purpose would be to reliably develop geologic sequestration at a system-wide scale. It should not compete with otherwise commercial operations, such as EOR, although it could conceivably help facilitate EOR through joint ventures. Its service territory would be comprised of a formation (or set of formations, such as a sedimentary basin) for which it would be desirable to have a single entity coordinate and manage the resource.

The central challenge facing geologic sequestration is how to scale up from a few test injections to the commercial injection of CO_2 from hundreds of sources in a region. A GSU would do several things to speed widespread commercial sequestration:

- *Scale:* It may take a decade to fully develop a single sequestration site. A GSU, funded by rate recovery, would have the resources to develop many sites simultaneously, making it possible to receive CO_2 from multiple stationary sources.

- *Reliability*: A GSU would offer a reliable, “over-the-fence” CO_2 sequestration option for power plants and other stationary sources, allowing them to focus on their core businesses.

- *Efficiency*: A GSU could better manage issues arising from multiple projects, including transparency, selecting and characterizing storage sites, acquiring property rights, and addressing property damage and other liability issues.

- *Financing:* A GSU would be able to ensure stable funding for sequestration and manage costs through ratemaking.

- *Liability*: A GSU would free electric generators from potential liability concerns by creating a public utility capable of recovering (through rates) the funds needed for any remedial action.

Recommendations

The cost reduction phase rests upon three key elements: GHG emissions performance standards for new and existing fossil fuel–fired electric generating units, along with some combination of carbon prices and substantial incentives for CCS deployment, distributed through a reverse auction.

Financial Incentives

Recommendation 11: *The administration should support efforts in Congress to create a significant package of financial incentives for CCS deployment*, which should:

- Drive deployment of *at least 50 GW of CCS*. That is the scale needed to drive costs down to the level expected from a mature industry. This initiative would be expected to fund CCS projects coming on line between 2020 and 2040 at a cost of approximately $275 billion in nominal dollars in the coming decades. The actual incentive levels will vary by what would be anticipated under an economy-wide cap-and-trade program.

- Be distributed through a reverse auction, with separate auctions for specific technologies, such as gas power plants, underground coal gasification plants, or coal plant retrofits.

- Be available for both coal and gas power plants.

- Be performance-driven, provided to projects based on tons of CO_2 sequestered.

- Establish a credit reservation system, providing for a conditional commitment of an incentive to a project, which should be developed in order to facilitate project finance.

Performance Standards

Recommendation 12: In the absence of climate legislation, EPA must propose in spring 2011 (and finalize by 2012) GHG emissions performance standards required by the Clean Air Act section 111(b)[13] for new coal plants, based on emissions levels that can be reached through the application of CCS technology:

- New coal plants permitted after January 1, 2011 should be required to meet a CO_2 emissions rate of 550 lbs/MHW.

- New coal plants permitted after January 1, 2020 should be required to meet a CO_2 emissions rate of 275 lbs/MHW.

[13] 42 U.S.C. § 7411(b).

Recommendation 13: In the absence of legislation by January 2011, EPA must propose in spring 2011 (and finalize by 2012) a GHG emissions performance standard for new natural gas power plants under Clean Air Act section 111(b),[14] based on emissions levels that can be reached through application of CCS. This standard should be designed to require deep reductions of carbon dioxide from the power sector during the coming decades.

CATF is exploring specific options to recommend for the structure, emissions targets, and timing of GHG emissions performance standards for new natural gas power generating units.

Recommendation 14: In the absence of legislation by January 2011, EPA must propose in spring 2011 (and finalize by 2012) regulations directing states to implement a program of GHG emissions performance standards for existing coal and gas plants under Clean Air Act section 111(d),[15] based on emissions levels that can be reached through the application of CCS. This program, even if it includes a sector-based emissions trading system, *must* be designed to require deep reductions of CO_2 emissions from the power sector in the coming decades.

CATF is exploring specific options for the precise structure, emissions targets, and timing of GHG emissions performance standards for existing coal power generating units.

Geologic Sequestration

Recommendation 15: Establish a federal program to support the creation of regulated public utilities designed to facilitate geologic carbon sequestration. This program would allow states to create such utilities, or, if necessary, establish such entities where they are needed. The Geologic Sequestration Utilities program should have the following elements:

- The ability of states, individually or in coordination, to assert jurisdictional primacy, with federal authority asserted if states do not act to develop the sequestration resource

- A national assessment and identification of geologic regions of saline formations suitable for management by a single entity

- Federal authority to offer certificates of territorial authority to manage geologic sequestration regions and provide cost recovery through rates, as well as a risk-based rate of return

---

[14] Ibid.
[15] 42 U.S.C. § 7411(d).

- Oversight of the utilities resource management, through a management plan that would ensure total basin sequestration capacity is maximized, interference between projects is minimized, and back-up capacity is available to avoid interruptions in CO_2 off-take.

- Assumption of all project liability from emitters and transporters of CO_2 external to the utility.

International CCS Recommendations

CATF recommendations for international collaboration focus on China. CATF is working in China and elsewhere in Asia to speed a global transition to low-carbon coal technology, by facilitating the development of joint business ventures between innovative energy companies and research institutions in Asia and the West.

CATF believes that *creating linkages or partnerships* between companies from China and the West are crucial to accelerating the commercialization of low-carbon coal-based energy generation. The countries' shared reliance on coal creates many challenges—along with some critically important opportunities. Energy companies in North America, Asia, Europe, and Australia have enormous experience and expertise working with coal, and are similarly motivated to develop technologies and techniques that will preserve a role for coal in a carbon-constrained world.

The table below summarizes some of the coal and CCS partnerships that have been announced in the last eighteen months.

Southern Company/KBR–Dongguan Tianming Electric Power Company

- Atlanta-based Southern Company will deploy the KBR-developed Transport Integrated Gasification technology (TRIG) in a commercial-scale coal gasification plant operated by Dongguan Tianming Electric Power Co. in China.

- The terms of the agreement include technology licensing, engineering, and equipment to use TRIG technology at a new 120 MW power plant. Operation is expected to begin in 2011.

Duke Energy–ENN Group

- A September 2009 agreement between Duke and ENN Group of China promoted joint technology development of a variety of technologies, from CCS-relevant systems, including underground coal gasification, to solar, biofuels, and energy efficiency.

ZEEP–ENN Group

- Zero Emission Energy Plants Ltd. (ZEEP) and ENN Group agreed in September 2009 to design and construct a commercial-scale power plant in Shandong Province featuring Connecticut-based Pratt & Whitney's

Rocketdyne gasification system.

Future Fuels–Thermal Power Research Institute

- Houston's Future Fuels has licensed TPRI's multi-stage, dry-feed, waterwall coal gasification system, which is also being installed at the GreenGen IGCC project in Tianjin.

- Future Fuels plans to use the technology at its Good Spring IGCC project in Pennsylvania, which it expects will deliver 270 MW of electricity while capturing over 50 percent of the CO_2 output initially and nearly 100 percent by 2020.

- The companies have also signed an agreement to share technical data from Future Fuels' Good Spring plant and TPRI's GreenGen facility.

Duke Energy–China Huaneng Group

- The two companies signed a technology-sharing MOU in August 2009 outlining potential areas of collaboration including "(1) clean coal power generation with the focus on IGCC and Ultra Supercritical power generation, (2) CO_2 Capture and Sequestration (CCS) including Pre-combustion Capture, Post-combustion Capture, Enhanced Oil Recovery (EOR) and geologic sequestration, etc.," and other investments in energy efficiency and renewable energy generation.

HTC PureEnergy–Suntracing Clean Energy

- Canada's HTC is working with Suntracing in China to demonstrate modular technology developed by HTC that uses CO_2 captured from power applications to produce a fire-suppressing foam; the foam is then used to put out coal seam fires, which are common in China and a significant contributor to global CO_2 emissions.

Clearly, the environmental and economic benefits of transitioning to clean energy will be smaller and slower to materialize if western and Chinese companies do not work together. The climate challenge will be solved by multiplying opportunities for rapid development and deployment of low-carbon generating technologies, not by restricting engagement between companies in the world's most dynamic economies. Investments by one country reduce the cost of that technology worldwide, increasing the likelihood that CCS will be widely deployed in time to help avert the worst consequences of climate change.

Recommendation 16: *The federal government should create a $500 million CCS Deployment Fund, to be spent over five years, to support American companies' participation in international CCS partnerships.* The Deployment

Fund would be administered by a quasi-federal entity that has experience financing involvement by U.S. companies in international energy projects.

- The Deployment Fund should support CCS projects arising from collaboration between energy companies and research labs from both countries. Proposals jointly developed by American and Chinese businesses and research institutions, rather than government agencies, will help forge the type of private-sector partnerships that have proved to be most effective at advancing CCS development.

- The funding should be used to commercialize three key carbon management processes: geologic carbon sequestration (GCS), post-combustion capture (PCC), and underground coal gasification (UCG).

    - The fastest and least expensive way to develop necessary expertise in geologic sequestration is to start with the "capture-ready" CO_2 currently being vented by numerous coal gasification facilities in China. GCS projects would have to sequester at least 500,000 tons CO_2/year to qualify for support.

    - Support for PCC should initially focus on scaling up pilot projects; subsequent funding would be used to deploy PCC (linked to some form of GCS) at one or more commercial-scale power plants.

    - At the right site, UCG with CCS has the potential to significantly reduce the cost of decarbonizing coal-based energy generation. Qualifying UCG projects should have a minimum gross installed capacity of 100 MW.

Funding should be reserved for projects in either country capable of beginning construction within eighteen months of application approval, with priority given to NowGen projects capable of implementing CCS technologies quickly and at commercial scale.

Research and Development Recommendations

Throughout the pioneer, cost reduction, and mature industry phases of CCS development, the federal government will need to make investments in CCS research, development, and demonstration (RD&D). This research could be especially important in accelerating learning and, ultimately, reducing costs. These recommendations are described in detail in CATF's 2009 report, *Coal Without Carbon: An Investment Plan for Federal Action*, which includes expert contributions from researchers at MIT, Tufts University, Lawrence Livermore National Laboratory, and private project developers. The full report is available at http://www.catf.us/resources/publications/view/101.

Key areas for RD&D identified in *Coal Without Carbon* include advanced post-combustion capture technology, advanced modeling and monitoring for UCG processes, and accelerated learning in GCS. These are highlighted below.

Advanced Post-Combustion Capture Technology

Achieving maximum cost reductions for post-combustion CO_2 capture could depend on development of breakthrough approaches and technologies that are not currently in the marketplace, or even a part of mainstream thinking. Examples of such novel approaches include amine compounds immobilized in solid sorbents, polymeric membrane absorbents, metal organic frameworks, structured fluids such as hydrates, liquid crystals, and ionic liquids, and novel technologies like non-thermal solvent regeneration, as well as advances to existing amine- and ammonia-based technologies.

Recommendation 17: *Provide federal funds to establish an advanced PCC technology RD&D pipeline* with the following key features:

- A ten-year funding period and planning horizon
- Support for up to *fifty bench-scale research systems* (2.5 tpd/0.1 MW), with $1 million allocated per project
- Support for up to *thirty proof-of-concept systems* (25 tpd/1 MW), with $10 million allocated per project
- Support for up to *fifteen pilot-scale systems* (250 tpd/10 MW), with $50 million allocated per project
- Rigorous evaluations of the technical and commercial potential of each technology prior to advancement from one scale to the next

- Flexibility to draw particular technologies into the pipeline, or to graduate technologies out of the pipeline, as circumstances warrant

Advanced Modeling and Monitoring for Underground Coal Gasification

Although in many ways UCG is a commercial technology today, gaps in the understanding of some basic physical and environmental processes occurring during UCG operations could limit the potential for its safe and efficient deployment in the near term. A relatively modest RD&D program would advance UCG understanding significantly.

Recommendation 18: *Establish a federal program to conduct UCG process simulation, monitoring tool development, and testing*. The program would likely cost $122 million over four years, and should have the following components:

- A publicly funded UCG experimental station and operating in-situ reactor test-bed

- Development of UCG process simulation capacity that captures the full range of the coupled geophysical, chemical, and hydrological processes occurring during UCG

- Adaptation of existing geophysical monitoring tools (e.g., microseismic monitoring, interference synthetic aperture radar [InSAR], and electrical resistance tomography [ERT]) to the UCG context

- Testing and refinement of the modeling and monitoring tools at the functioning experimental station and operating reactor

Accelerated Leaning for Geological Carbon Sequestration

There is a rapidly growing knowledge base for geological carbon sequestration around the world, and many projects and programs are exploring important issues in the field. One element missing from most programs, however, is accelerated learning based on rapid iteration, at large scale, in an experimental (as opposed to commercial) context. Notionally, the concept is to use a large and publicly funded injection site capable of handling 5 million tons of CO_2 per year to allow experimentation in well-drilling and well completion techniques, reservoir management approaches, and simulation and monitoring technology, without the overhang of a commercial project (where operators must focus on reliable injection and verification of storage within prescribed limits, rather than experimentation and knowledge acquisition).

Recommendation 19: *The Department of Energy should establish a publicly funded GCS testing facility* with the attributes just described, an initiative which might cost $200 million over four years.

Appendix

NorthBridge Modeling Results

Full CCS Deployment

Economic and Policy Analysis for CATF by Northbridge

Bruce Phillips
Northbridge

Deployment
Key from the NorthBridge Analysis

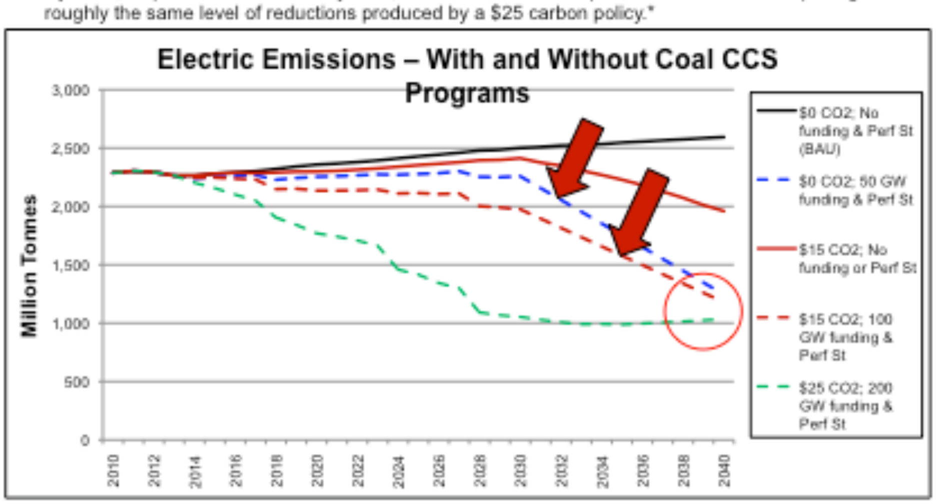
- ***CCS incentives for coal are essential to driving deeper and faster emissions cuts*** in the power sector than just carbon prices or coal performance standards alone.
- Experience with analogous technologies suggests that ***the U.S. should deploy at least 50 GW of all forms of CCS capacity to reduce costs***.
- ***Financial incentives are needed for*** large scale***, early year deployment*** regardless of the level of carbon pricing. While capital and O&M costs to not differ by policy, ***the required incentive levels are smaller with increasing carbon prices***
- A ***reverse auction is essential*** to cost effective deployment (more plants at lower costs).
- ***CCS on natural gas power plants*** may play a critical role in deep power sector emission cuts.
- ***Retrofits have a economic advantages over new builds***, but ***underground coal gasification may be a game changer for new builds and CCS costs in general***

Slide 37

Deployment
CCS and Coal

CCS, applied to existing coal units in the U.S.:

- Can drive deeper and faster carbon reductions than would otherwise occur (the likely alternative being retirement of the coal fleet over time and replacement primarily with gas generation.)
- By 2040, help reduce emissions by 50%, even with low carbon prices or without carbon pricing – roughly the same level of reductions produced by a $25 carbon policy.*

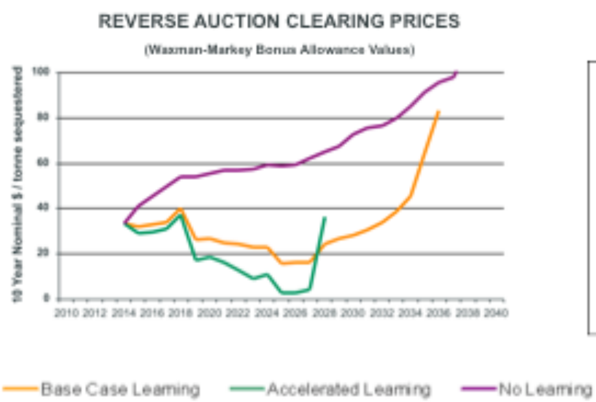


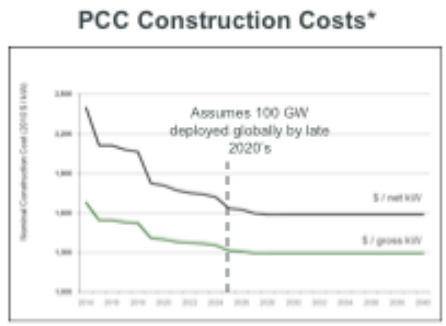
* Carbon prices expressed in 2014 $/Tonne and assumed to increase at 7%/year.

Slide 38

Deployment
Importance Of Learning

- The analysis shows that deployment programs can have a very large impact on program costs and the amount of capacity retrofit if they are well designed and effective. Experience with analogous electric technologies suggests that most CCS cost and performance improvements will be achieved by the time 100 GW is deployed globally.
- This suggests a U.S. deployment goal of 50 GW minimum of all forms of CCS is reasonable.
- This goal corresponds to 25 percent of the existing fleet of units greater than 200 MW.



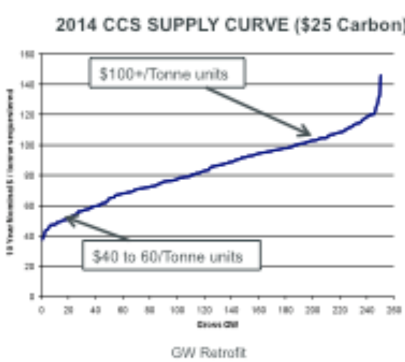


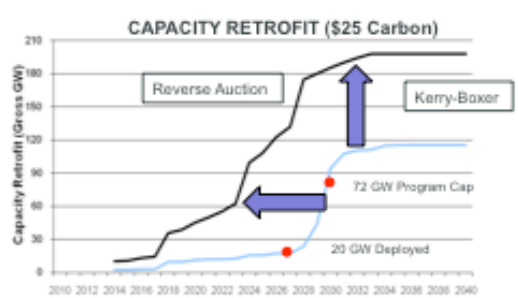
*2014 cost estimate is for a scale "Nth" unit, not a first-of-a-kind demonstration project.

Slide 39

Deployment
Allocating Incentives with Reverse Auctions

- Because the coal fleet is diverse – with a range of coal types, conventional pollutant controls, unit sizes, access to EOR revenues, etc. – the cost to apply CCS varies widely from unit to unit.
- Reverse auctions capitalize on this variation and, coupled with a rapid transition from early action to deployment, are essential to cost effective deployment, roughly doubling the capacity deployed under one legislative proposal
- Holding separate auctions for projects receiving EOR revenues and others incurring transport and sequestration costs is important to encourage early deployment in regions of the country, such as the Midwest, without easy access to EOR.

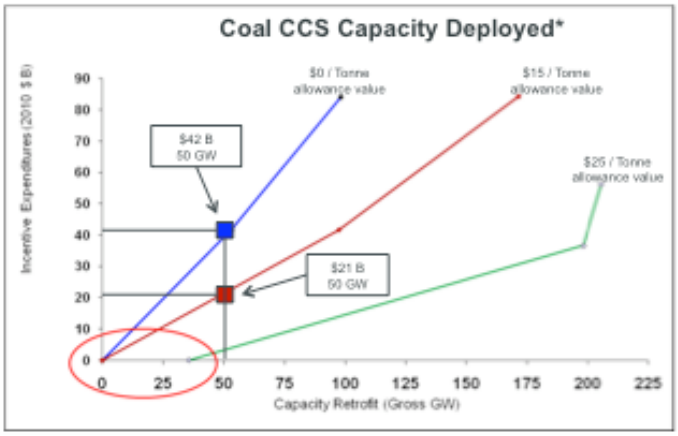




Slide 40

Deployment
Incentives & Carbon Pricing

- Incentives are needed for large scale, early year deployment. Without them, little if any CCS will be deployed before 2030 regardless of the level of carbon allowance prices;
- Carbon pricing, in addition to providing program funding, reduces the level of incentives required
  - ➢ It does not directly reduce the capital and operating costs of CCS retrofits
  - ➢ Instead, it allows a portion of the CCS costs to be covered by the carbon market, reducing the amount that must be paid for by an incentive.**



CCS Cost ($ / Tonne)		
	Allowance Price	
	$ 0	$ 15
Total	75	75
Incentive	75	45
Market	0	30

* Assumes incentives are allocated using a reverse auction process
$21 and $42 B estimates translate to $138 and $275 B in nominal terms between 2014 and 2040.
** Many other considerations also factor into any decision regarding the benefits and issues associated with carbon pricing.

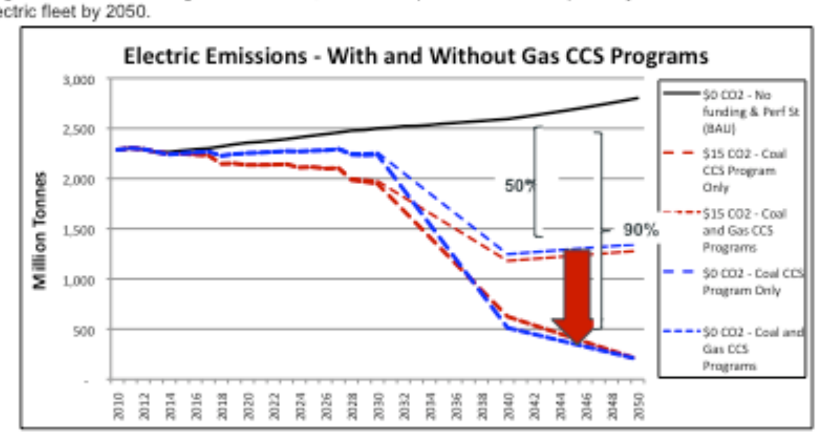
Slide 41

Deployment
CCS and Natural Gas

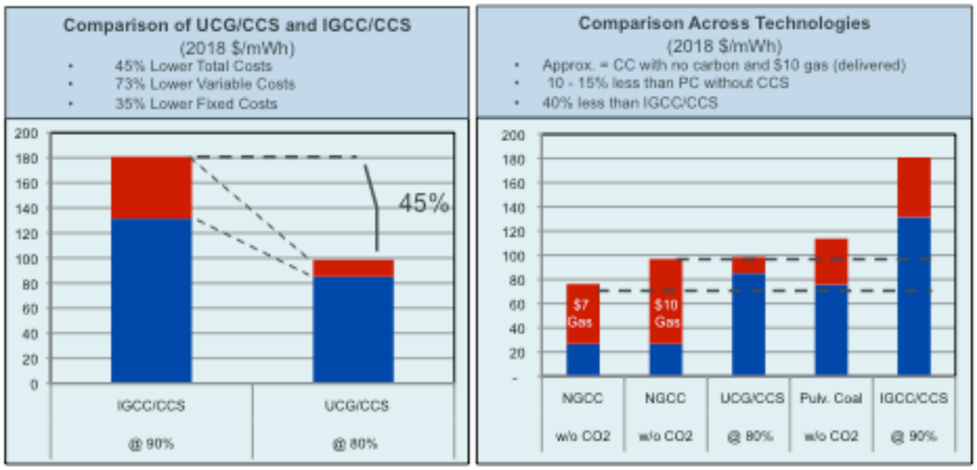
To de-carbonize the entire U.S. the electric sector by 2050, other abatement options will be needed:

- Gas combined cycles with CCS – which would be a low cost option if unconventional gas materially dampens prices or there is limited improvement with renewable and nuclear technologies – could drive 90% emission reductio
- UCG with CCS, at roughly $100/mWh, could be an even lower cost carbon-free resource.

By making these fossil technologies carbon-free, CCS could provide a low cost pathway to de-carbonize the entire electric fleet by 2050.



Slide 42



Note: UCG cost estimate based on proprietary data supplied to The NorthBridge Group by a private project developer.

Slide 43

Deployment
Key Issue of Performance Standards

- Performance standards are an important complementary policy tool, for both coal and gas:
  - Provide environmental certainty
  - On coal alone, can drive 50% sector reductions. On gas as well as coal, can drive 90% sector reductions
  - Regardless of the level of carbon prices
  - Provide a greater level of financial certainty to fossil unit investors
    - For owners of existing coal and gas units considering retrofits and life-extensions
    - For investors in new fossil units
  - Establish price benchmark –
    - On new gas units, would establish a new benchmark for cabon-free wholesale market prices
    - Stimulating demand for renewable and nuclear alternatives. *

- At least in concept, a simple policy of performance standards on new and existing fossil units could produce very substantial carbon emission reductions, even in the absence of a carbon price.

* Whether applied in concert with carbon pricing and incentives or alone, the timing and stringency of standards needs to be considered in light of the infrastructure requirements and market impacts.

Slide 44

Modeling Approach

CATF retained the NorthBridge Group to model the cost levels and policy scenarios of CCS deployment on U.S. fossil-burning power generation units (coal and gas). The NorthBridge Group is an economic and strategic consulting firm serving the electric and natural gas industries, including both regulated utilities and companies active in the competitive wholesale and retail markets.

The approach taken to this CCS analysis by the NorthBridge Group is unique, including:

- Unit-by-unit look at existing capacity,[16] not generic or typical units
- Market dispatch in regional power markets, not uniform base-load operation
- Current outlooks for gas, coal, capital, and other economic assumptions
- Investments and retirements based on economics rather than unit age or size
- CCS cost and performance estimates derived from DOE/NETL studies
- "Nth" commercial projects, not today's demonstration projects
- Adjustments for changes in capital costs since studies were conducted
- Technology learning rates based on Carnegie Mellon work, reflecting view that improvements are more likely to be incremental than "step change" breakthroughs

The modeling system used by the NorthBridge Group in its work for CATF is structured around two main models. The first of these is FastForward, a commercially available fundamental dispatch and wholesale market price forecasting tool developed by the NorthBridge for EPRI and used by investor-owned utilities, competitor generators, load-serving entities, and consulting firms in the United States. The second is a proprietary emissions compliance planning model that builds on output from FastForward to estimate emissions compliance retrofit and unit retirement decisions.

---

[16] Specifically, the 1,489 units in the Eastern Interconnection and ERCOT that represent 89 percent of U.S. coal capacity. Eastern Interconnection and ERCOT results are scaled to calculate national figures. Industrial coal facilities have not been evaluated.

FastForward is a PC-based VisualBasic model designed to rapidly generate forward market prices for electricity on a probabilistic basis. At its core, it is a multi-region dispatch model that quickly estimates hourly electric market-clearing prices under an array of load, resource, and commodity scenarios. The model relies on a scenario generation module to identify statistically meaningful scenarios based on volatility and correlation parameters for each input variable. The market price outputs derived for each scenario describe a sample distribution from which a variety of statistics is calculated. In addition to the *expected market price trajectory*, the statistical estimation module can calculate *the probability distribution associated with market prices and correlations with other variables*.

FastForward is used by major investor-owned utilities, competitive generating companies, load-serving entities, and consulting firms in the United States to forecast market prices, assess generating asset market values, and develop risk management plans.

For the purpose of this effort, FastForward is run on a deterministic basis to *produce hourly pricing results for the power grid reliability regions* shown on the attached map for a series of years between 2010 and 2040.

The emissions compliance planning model takes unit-specific generating data and regional hourly market price results from FastForward, along with cost and performance assumptions for carbon capture and sequestration (CCS) and SOx and NOx emissions control technologies. It then *estimates unit retirement and emissions control retrofit decisions annually under alternate commodity assumptions and regulatory scenarios*. The regulatory scenarios include variations on the CCS deployment provisions proposed in Waxman-Markey, Kerry-Boxer, and by others including CATF. The compliance model is easily adapted to evaluate the impact of potential new conventional pollutant policies, with or without carbon pricing policies. The model also uses unit retirement decision rules that are based on economic criteria tailored to the regulated and merchant ownership status of individual units, rather than engineering or physical unit criteria (age, for example). The intent of this is to more accurately reflect the manner in which unit owners operate.

Cost Effectiveness of CCS Compared to Other Technologies

CCS Deployment Costs and Cost-Effectiveness

Key questions regarding CCS costs include:

1. How cost effective is CCS compared to other sources of carbon-free power?

2. What fraction of CCS costs should be covered by an incentive program?

3. What is the relative scale of CCS incentive cost, compared with overall electricity costs or other technology incentives?

Cost Effectiveness of CCS

CCS cost effectiveness can be compared to other carbon abatement options, especially within the context of a portfolio of technology initiatives. A broad cross-technology comparison of carbon abatement potentials is beyond the scope of this review. However, the following cost-per-ton comparison of carbon abated by CCS and by wind suggests that CCS can be at least as cost effective as wind. This suggests that it is reasonable to include CCS among a portfolio of carbon-free technologies that should be deployed over the next five to ten years.

The chart below shows two estimates of the $/tonne cost of carbon abated by today's onshore wind technologies, both primarily based on recent DOE EIA data, along with four comparable estimates for CCS retrofits on coal units.

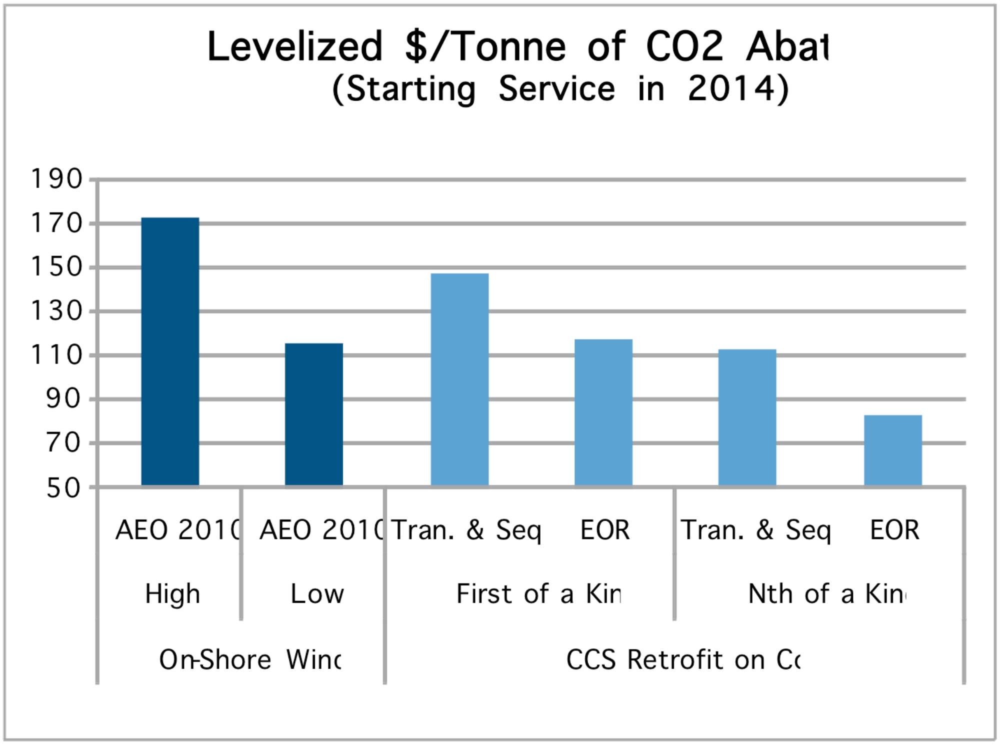
- The wind estimates range between $115 and $175/tonne.

- In comparison, first-of-a-kind (FOAK) CCS retrofit projects are estimated to cost between $120 and $150/tonne, well within the range of the wind estimates.

- Nth-of-a-kind CCS retrofit projects, such as are expected to be available at the end of the pioneer phase of industry development and at the start of the cost reduction phase, are estimated to range between $85 and 115/tonne, which is 25–35 percent below the cost of the current wind estimates.

- Deployment of CCS technologies during the cost reduction phase is expected to result in further cost reductions and performance improvements, perhaps on the order of another 25–30 percent.

.



* Both cost estimates for wind are based on DOE EIA AEO 2010. The first is taken directly from EIA's "Levelized Cost of New Generation Resources" and escalated to 2014 dollars. The second is calculated using assumptions in AEO 2010, table 8.2. Wind PTC, ITC, and accelerated depreciation subsidies are not included. CCS cost estimates are derived from DOE NETL cost and performance assumptions and current project proposals and include replacement purchased power. Both wind and CCS projects are assumed to be located in a natural gas–driven electric market.

It is also worth noting that DOE estimates the cost of offshore wind to be materially higher than onshore wind, on a national average basis, even taking into account the higher expected capacity factors.

Finally, in the context of developing a portfolio of carbon abatement options, it is reasonable to include CCS as one of three main electric generation abatement options, along with renewable and next-generation nuclear technologies. CCS can be at least as cost effective an abatement option as today's wind technologies and has the added benefit of being a dispatchable baseload resource, whereas wind and some other renewable resources are intermittent in nature. Based on these and other important policy reasons to deploy CCS, further investment in developing and deploying CCS technologies is warranted as part of a portfolio strategy.

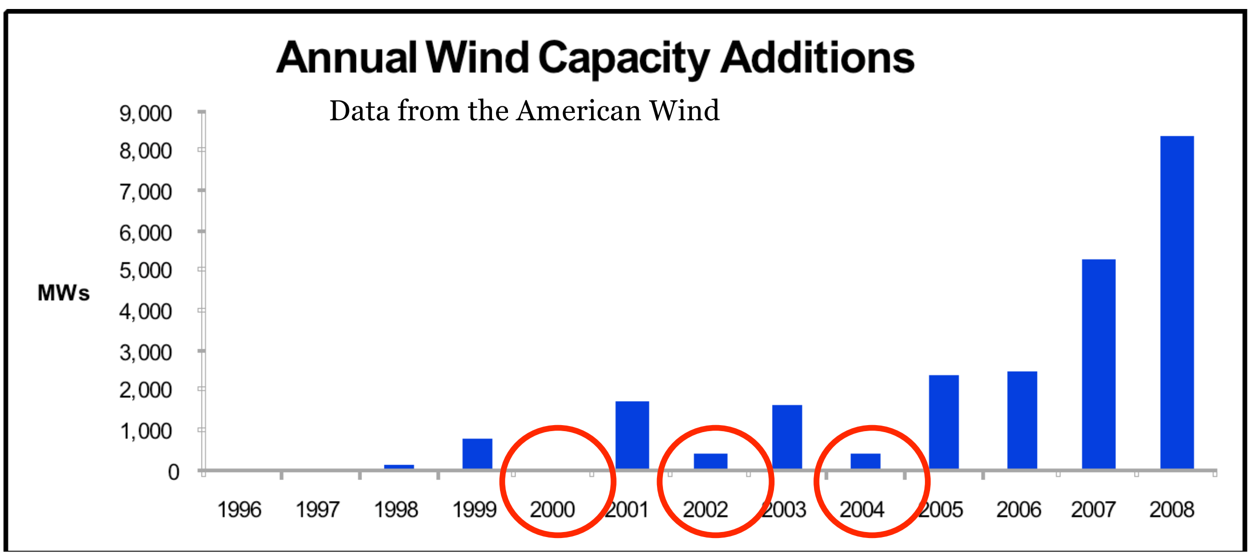
Importance of Covering All Incremental Costs of Deployment

A key issue related to program costs is whether an incentive should cover just a portion of the incremental costs required for deployment (as is done today under the cost-sharing approach used in DOE's CCPI program) or instead cover all the incremental costs required for deployment.

While some federal technology programs have historically provided financial support on a cost-sharing basis, there is also precedent at the federal level for incentives to cover the full amount required for deployment. The history of these latter programs shows that full compensation is a much more effective path to deployment.

For example, the production tax credits (PTCs) and accelerated depreciation schedules provided to wind energy technologies are frequently sufficient to cover the full amount of financial support needed for deployment. This does not mean they are sufficient to cover all capital costs, just sufficient to cover the cost premium of these technologies compared to local wholesale market prices. Since the incentives are sufficient to cover the full amount needed for deployment, there is, in effect, no cost sharing for wind technologies as there is in some DOE technology programs. Further, the lack of wind deployment in the years in which those incentives were not sufficient is evidence of their importance to effective deployment.

This point is supported by DOE in its 2008 *Wind Technologies Market Report*, which states, "The importance of the PTC to the U.S. wind industry is illustrated by the pronounced lulls in wind capacity additions in the three years (2000, 2002, and 2004) in which the PTC lapsed, as well as the increased development activity often seen during the year in which the PTC is otherwise scheduled to expire—one of the reasons for the enormous capacity expansion witnessed in 2008." This is illustrated in the following figure.

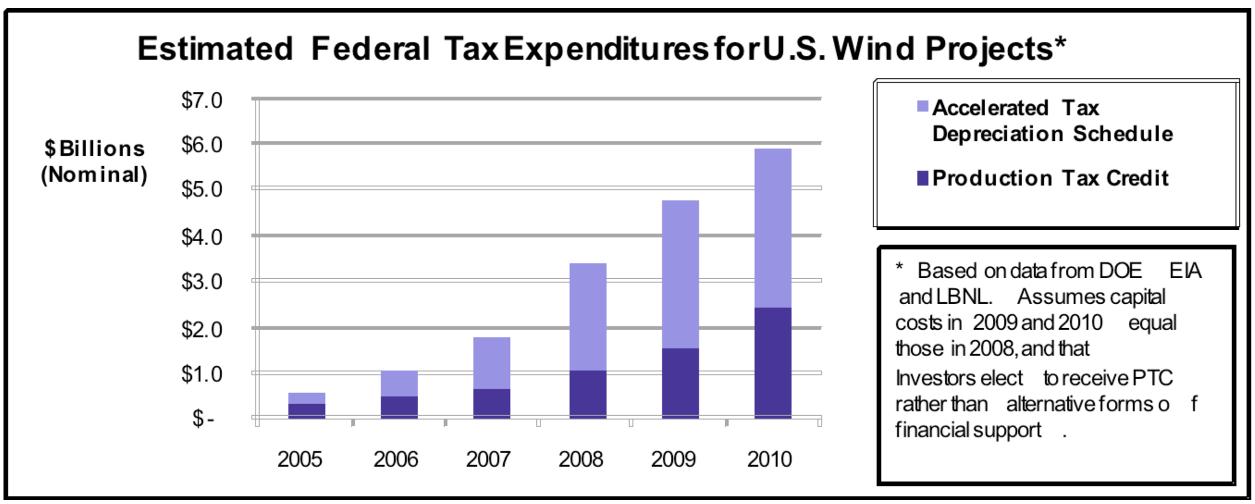


Because of this type of experience with technology deployment programs, as well as the large capital investments required to deploy CCS, there is little if any reason to believe the program's deployment goal will be met under a cost-sharing approach.[17] For this reason, if sufficient funding is not available to fully support the incentives required to achieve the deployment goal, it would be preferable to fully fund the incentives required for a smaller deployment goal than to partially fund a larger deployment goal.

Relative Scale of CCS Incentive Costs

The cost of incentives recommended for the pioneer program is $20 billion in 2010 dollars through 2020, and the estimated cost for a deployment program is $275 billion in nominal dollars through 2040. In relative terms, that's about 2.7 percent of total projected power-sector generation costs through 2040, and about 1.5 percent of average residential electric costs.

The scale of these costs can also be understood in comparison to the incentive costs being incurred today to commercialize wind technologies. The proposed total pioneer program cost of $20 billion in 2010 dollars corresponds to $3.3 billion annually averaged over a six-year period and $1.0 billion per year for a twenty-year period As shown in the figure below, the six-year annual average of $3.3 billion is little more than half the roughly $6.0 billion estimated to support the wind industry this year, which now stands at roughly 39 GW, according to EIA.



[17] Imposition of a GHG emissions performance standard or other forcing mechanism (e.g., a clean energy standard, like a renewable portfolio standard) might result in some additional deployment.