Addressing Emissions From Coal Use in Power Generation

Coal is a cheap and abundant resource, and carbon dioxide (CO_2) from coal use is responsible for about 40 percent of global greenhouse gas (GHG) emissions from fossil fuel use. The United States and China are by far the largest emitters of CO_2 from coal consumption, accounting for nearly 60 percent of global CO_2 emissions from coal, with India a distant third. The United States currently relies on coal for roughly half of its electricity generation resulting in roughly one third of total U.S. emissions. China generates 80 percent of its electricity from coal, and in recent years, emissions from coal use have grown five times faster in China than in the United States. With enough coal reserves to meet current consumption levels for centuries, the United States and the rest of the world face the challenge of reconciling the realities of coal use with the dangers posed by climate change.

Carbon capture and storage (CCS) is a means to meet this challenge. If widely deployed, CCS could allow the world both to continue to exploit its cheap and abundant supply of coal and to adequately address the threat of climate change. CCS works by separating CO_2 from other gases in the exhaust stream at power plants and industrial facilities, compressing the CO_2 to pressures suitable for pipeline transport, and injecting the CO_2 into deep geologic formations where it can be safely and indefinitely stored.

Although components of the CCS suite of technologies have been used in a variety of situations, the entire suite has not been deployed at a commercial scale at any coal-fueled power plant to date. Deployment has not proceeded for a number of reasons, primarily the high costs of installing and operating CCS technologies and the absence of government policies that place a financial cost on GHG emissions. In addition, uncertainties remain concerning actual cost and performance of CCS technologies at commercial scale. Finally, CCS deployment requires an appropriate regulatory system for CO_2 storage, including long-term liability.

This brief describes the potential role of government in facilitating widespread and more rapid deployment of CCS through a number of means including: providing financial incentives for initial CCS projects through the use of bonus allowances under a cap-and-trade program, or a fund generated by charges on electricity or fossil-fuel based sources of electricity; setting GHG emission performance standards for coal generators or electricity providers; and establishing the required regulatory and liability frameworks for CO_2 storage.

Half of all U.S. electricity generation is fueled by coal.[1] The United States likely has sufficient coal reserves to support current levels of consumption for at least 100 years, and perhaps as long as 250 years or more.[2] Russia, China, India, and Australia also all possess large coal reserves, and greenhouse gas (GHG) emissions from coal use are growing rapidly in India and China (see Table 1 on page 2). Coal is a relatively inexpensive source of energy. The U.S. Energy Information Administration (EIA) estimates that average 2008 energy prices put coal at $1.89 per million British thermal units (MMBtu) compared to $11 and $21 per MMBtu for natural gas and oil, respectively.[3] In addition, coal prices are generally less volatile than those of either oil or natural gas. Unlike renewable energy technologies, such as wind and solar power, coal-fueled power plants can reliably provide large amounts of baseload electricity generation. While nuclear power can provide reliable baseload electricity generation without

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GHG emissions, nuclear power faces its own challenges, including public siting concerns, large and uncertain construction costs, and waste disposal and proliferation issues.

Coal use accounts for roughly one third of total U.S. GHG emissions and 80 percent of emissions from the U.S. electric power sector both because coal is a major source of energy and because coal use emits higher levels of carbon dioxide (CO_2) per unit of energy than other fuels.[4] For instance, combustion of coal emits 1.7 times as much CO_2 per MMBtu as natural gas combustion.[5] Given the high rate of CO_2 emissions from coal combustion, coal's large contribution to total emissions, and the likelihood that coal will continue to provide a large amount of U.S. and global energy, any program to reduce GHG emissions to levels adequate to address climate change will need to achieve significant reductions in the emissions from the use of coal.

Coal plays as important a role in world energy supply and global GHG emissions as it does in U.S. energy supply and emissions. In 2005, CO_2 emissions from coal combustion accounted for 40 percent of global CO_2 emissions from fossil fuel use.[6] China and the United States are by far the largest emitters of CO_2 from coal combustion, together accounting for nearly 60 percent of global CO_2 emissions from coal use, with India a distant third (see Table 1). In China and India, coal use accounted for 82 percent and 68 percent, respectively, of all CO_2 emissions from fossil fuel use in 2005.[7] From 1995 to 2005, CO_2 emissions from coal combustion grew nearly five times as fast in China and twice as fast in India as they did in the United States.

Table 1 *Statistics for Top 10 Coal-Using Nations*

	CO_2 Emissions from Coal Use (2005)				Coal Reserves (2007)	
Country	Emissions from Coal Use ($MtCO_2$)	% of Global Coal CO_2 Emissions	10-Year CAGR of Coal CO_2 Emissions in %	% of Fossil Fuel CO_2 Emissions from Coal	Proved Coal Reserves (% of World Total)	R/P Ratio
China	4,341	38	6.4	82	14	45
United States	2,142	19	1.3	36	29	234
India	791	7	2.7	68	7	118
Russia	442	4	0.4	26	19	500
Japan	417	4	4.6	34	—	—
South Africa	348	3	2.2	82	6	178
Germany	318	3	-0.4	38	1	33
Australia	232	2	5.1	57	9	194
Poland	199	2	-1.9	70	1	51
South Korea	196	2	6.7	39	—	—
Rest of World	1,933	17	2.0	19	16	136
World Total	**11,357**	**100**	**3.3**	**40**	**100**	**133**

Notes: $MtCO_2$ = 1 million metric tons of CO_2. CAGR = compound annual growth rate. Proved reserves are those recoverable under current economic and operating conditions from known deposits. R/P Ratio = the ratio of end-of-year proved reserves to annual production, which is a measure of how long a nation's coal reserves will last it. Coal reserves data were omitted for Japan and South Korea due to very low reserves and large reliance on imported coal.

Sources: EIA, *International Energy Annual 2005*, October 2007. BP, *Statistical Review of World Energy*, June 2008.

Though not yet commercially available for coal-fueled power plants, technologies do exist that can prevent most of the CO_2 emissions from large point sources that combust or gasify coal from entering the atmosphere. The technologies, referred to collectively as carbon capture and storage (CCS), involve separating CO_2 from other exhaust gases, compressing the CO_2 in order to transport it through pipelines, and storing it deep underground to prevent its release into the atmosphere indefinitely. As discussed below, several obstacles have so far prevented investments in large-scale CCS projects, but government incentives and regulation could enable the widespread deployment of CCS commensurate with GHG emission reduction goals under a U.S. climate policy.

Coal use accounts for roughly one third of total U.S. GHG emissions.

Overview of Carbon Capture and Storage (CCS)

This brief focuses on the integration of CCS with coal-fueled power plants; however, CCS could also be deployed with other large sources of CO_2 emissions. There are three approaches to carbon capture from coal-fueled power plants: pre-combustion, post-combustion, and oxyfuel combustion. In pre-combustion carbon capture, coal is gasified (rather than combusted) to produce a synthesis gas, or syngas, consisting mainly of carbon monoxide (CO) and hydrogen (H_2). A subsequent shift reaction converts the CO to CO_2, and then typically a physical solvent separates the CO_2 from H_2. For power generation, pre-combustion carbon capture can be applied to an integrated gasification

Box 1 *China and Coal*

In 2005, China was responsible for 38 percent of all global CO_2 emissions due to coal use, and China's emissions from coal are growing rapidly (see Table 1). China relies even more heavily than the United States does on coal for electricity generation. In 2005, roughly 81 percent of China's electricity came from coal-fueled power plants, and China has a large number of small, low-efficiency coal power plants.[8]

Modern high-efficiency coal plants and CCS could help China limit its GHG emissions from coal use. CCS projects are in development in China. GreenGen is a partnership between the Chinese government, Chinese energy companies, and Peabody Energy.[9] As planned, GreenGen will be deployed incrementally and will be a 400 MW-scale IGCC power plant with CCS by the end of the project's third phase in 2020.[10] A second CCS project in China, Near Zero Emission Coal (NZEC) is a partnership between China, the European Union, and the United Kingdom and has the goal of deploying a coal-fueled power plant with CCS by 2020. In June 2008, China Huaneng, a state owned energy firm, launched a post-combustion carbon capture demonstration project with technical support from Australia's Commonwealth Scientific and Industrial Research Organisation.[11]

In terms of CO_2 storage, pilot-scale geologic storage projects are underway in China (including CO_2-EOR projects).[12] Initial estimates of CO_2 geologic storage capacity have been performed and more detailed assessments of capacity are underway, including a multinational collaboration and research by PetroChina.[13, 14]

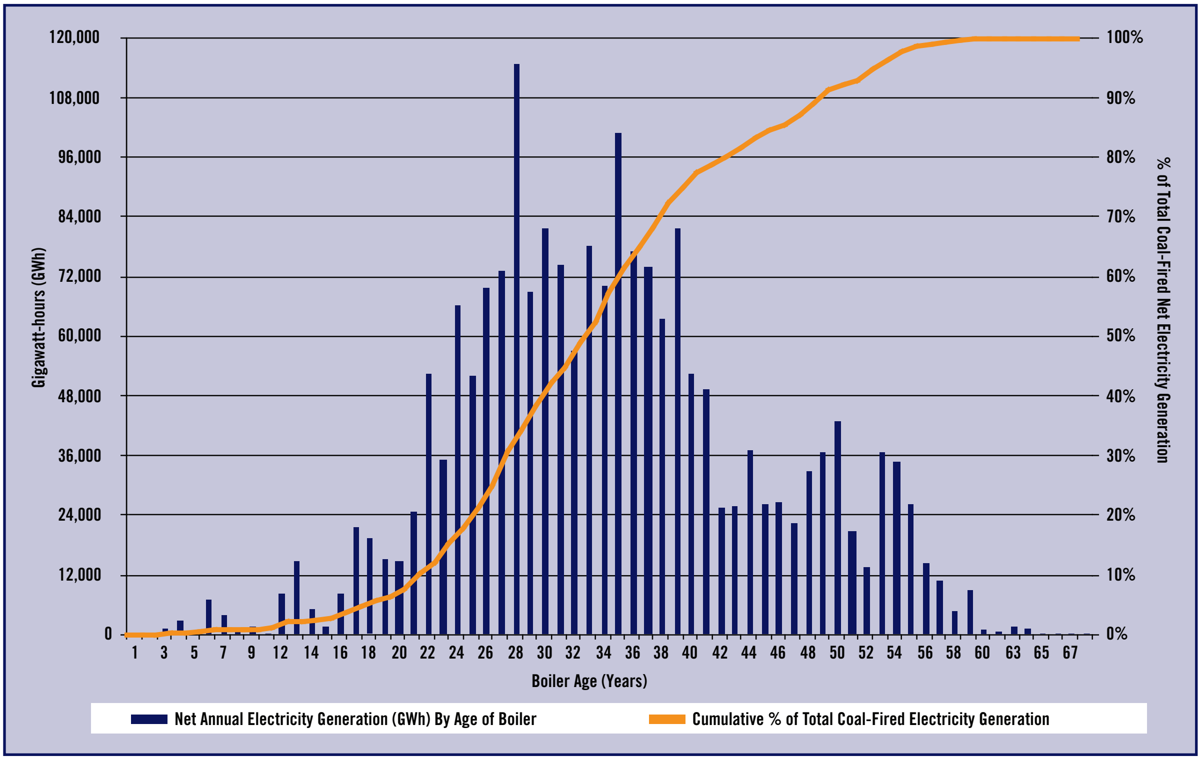
combined cycle (IGCC) power plant that burns the H_2 in a combustion turbine and uses the exhaust heat to power a steam turbine (the combustion of hydrogen does not emit CO_2). Post-combustion carbon capture typically uses chemical solvents to separate CO_2 out of the flue gas of a pulverized coal (PC) power plant. Oxyfuel carbon capture involves combustion of coal in pure oxygen (rather than air) so that the exhaust gas is CO_2-rich, which facilitates carbon capture.

Most coal-fueled power plants in the United States and around the world are PC plants. Only a handful of coal-fueled IGCC plants

Box 2 *Coal Plant Efficiency*

Improvements in the efficiency of coal-fueled power plants can greatly reduce GHG emissions. As shown in Table 2, most U.S. coal capacity was built prior to 1990; in fact, Figure 1 shows that 25 percent of electricity from coal power plants comes from boilers that are more than 40 years old. These older, less efficient units have higher CO_2 emissions per megawatt-hour (MWh) of electricity produced than plants built more recently. Current research and development (R&D) focused on advanced materials has the goal of enabling the construction of ultra-supercritical pulverized coal (USPC) plants with efficiencies of up to 47 percent—for comparison, plants built in the 1970s and 1980s have an average efficiency of only 36 percent.[15] These USPC plants would have CO_2 emissions roughly 20 percent lower per MWh than even new subcritical units.[16] Consequently, policies that encourage the construction of highly efficient plants can help limit GHG emissions from coal-fueled electricity generation.

Figure 1 *Net Annual Electricity Generation from U.S. Coal Power Plants by Boiler Age, 2005*



Source: NETL, *2007 Coal Power Plant Database*, see http://www.netl.doe.gov/energy-analyses/technology.html.

are in operation around the world; however, several new coal-fueled IGCC power plants are in various stages of development in the United States and elsewhere.[17]

The incremental cost of CCS varies depending on parameters such as the choice of capture technology, the percentage of CO_2 captured, and the type of coal used as fuel. As just one example, a 2007 study by researchers at Carnegie Mellon University estimated that, compared to an IGGC plant without CCS, an IGCC plant built with CCS that captured 90 percent of CO_2 emissions would produce electricity at a 42 percent higher levelized cost and reduce GHG emissions at a cost of $32 per metric ton of CO_2 avoided.[18] However, one should consider CCS cost estimates from engineering studies in light of the recent escalation in and uncertainty regarding capital costs in the power sector.[19, 20] New coal-fueled power plants (PC or IGCC) can be designed to incorporate CCS from the start of their operation, and existing plants can be retrofit for CCS. Retrofitting existing plants leads to higher costs for CCS compared to building new plants to incorporate CCS from the start since new plants designed for CCS can optimize their configuration for the additional equipment, processes, and energy necessary for CCS.

Captured CO_2 must be transported from its source to a storage site. Pipelines like those used for natural gas present the best option for CO_2 transport. CO_2 pipelines are a proven technology, and the United States already has more than 3,000 miles of CO_2 pipelines, mostly transporting naturally occurring CO_2 to enhanced oil recovery operations.[21, 22]

The most promising method of CO_2 storage is injection of CO_2 into deep underground geologic formations that can ensure safe, long-term CO_2 retention. The portion of injected CO_2 likely to remain in properly selected geologic formations is estimated to exceed 99 percent over 1,000 years.[23] The United States is fortunate in having geologic reservoirs with extensive storage capacity across much of the country. Less is known about the availability of suitable geologic reservoirs in China, but capacity assessments are underway. The largest potential for geologic storage in the United States is in deep saline formations, which are underground porous rock formations infused with brine; other options for geologic storage with lower storage capacity are depleted oil and gas reservoirs and unmineable coal seams (see Table 3).

Table 2 *Existing U.S. Coal-Fueled Power Plant Fleet by Vintage*

Plant Installation	Capacity GW	Efficiency %, HHV	CO_2 Emissions $MtCO_2$/Yr	CO_2 Intensity $MtCO_2$/MWh
Pre-1970	109	28	600	1.16
1970-1989	194	36	1,280	0.90
1990-2003	12	39	70	0.83

Notes: $MtCO_2$ = 1 million metric tons of CO_2.
HHV = higher heating value.

Source: Kuuskraa and Dipietro[24]

Table 3 *U.S. Geologic CO2 Storage Capacity Estimates*

Storage Type	Billion metric tons CO_2 Low	High
Oil and Gas Reservoirs	80	80
Unmineable Coal Seams	150	180
Deep Saline Formations	920	3,400
Total	**1,200**	**3,600**

Source: NETL, *Carbon Sequestration Atlas of the United States and Canada, 2007.*

In the United States, large stationary sources emit roughly 4 gigatons of CO_2 per year, and one can see from Table 3 that the United States could potentially use CCS for hundreds of years before depleting domestic storage capacity.

The U.S. Department of Energy (DOE) has been supporting regional partnerships focused on geologic CO_2 storage since 2003.[25] The partnerships are initiating large-scale tests to determine how geologic storage reservoirs and their surroundings respond to large amounts of injected CO_2 in a variety of geologic formations and regions across the United States. Worldwide, other large-scale projects for geologic CO_2 storage have been underway for a number of years, and monitoring has shown that the CO_2 is remaining safely in the target reservoirs.[26]

There is also the potential to use captured CO_2 for enhanced oil recovery (EOR). EOR using CO_2 involves the injection of CO_2 into oil wells to increase the amount of oil that can be extracted. EOR operators could conduct their efforts in a manner that stores the CO_2 injected into oil reservoirs. West Texas has a 30-year history of EOR using CO_2 though not using captured CO_2 and not explicitly for the purpose of CO_2 storage. EOR using captured CO_2 is underway at two projects in Saskatchewan, Canada.[27] There is significant potential for use of captured CO_2 for EOR, and revenue from selling captured CO_2 to EOR operators could help defray the cost of CCS as the first CO_2 emitters adopt the technology. A recent study estimated that from 2008 to 2030, oil producers could profitably use a cumulative total of 7.5 billion metric tons of captured CO_2 for EOR, which is more than three times the annual CO_2 emissions of all U.S. coal-fueled power plants.[28]

Importance of CCS

The availability of CCS significantly influences the GHG emission reductions that can be achieved at a certain cost (and, likewise, the cost of achieving a given level of emission reductions). For example, a computer modeling exercise found that having CCS available as a GHG mitigation option increased by 60 percent the emission reduction achievable at a specified carbon price.[29] The EPA's modeling analysis of the Lieberman-Warner Climate Security Act of 2008 (S. 2191) projected that under the proposed cap-and-trade program power plants with CCS would provide 28 and 38 percent of all U.S. electricity in 2030 and 2050, respectively.[30]

The availability of CCS significantly influences the GHG emission reductions that can be achieved at a certain cost.

EPA's analysis also predicted that delaying the date by which CCS technology can be deployed at commercial-scale power plants can greatly increase the costs of achieving GHG emission reductions under a cap-and-trade program; EPA's modeling found an increase in allowance prices of 40 percent when the assumed commercial availability of CCS was delayed from 2020 to 2030.[31]

Ensuring that CCS technology is demonstrated, well understood, commercially available, and unhindered by regulatory uncertainty at the earliest possible date will support the most cost-effective GHG emission reductions under a comprehensive climate policy, such as a cap-and-trade program.[32]

Obstacles to CCS Deployment

Firms have proven reluctant to invest in CCS given the absence of any financial cost associated with GHG emissions, uncertainty over the future regulations governing coal-fueled power plants and CO_2 storage, and the need for additional research, development and demonstration (RD&D) for CCS. Adding CCS technology to an existing or planned coal-fueled power plant requires additional investment which firms will not undertake in the absence of government technology standards or a policy that assigns a cost to GHG emissions. A cap-and-trade program, such as that proposed in S. 2191 (discussed above) or its successor, the Boxer-Lieberman-Warner Climate Security Act of 2008 (S. 3036) effectively puts a price on GHG emissions. Without a cap-and-trade or other regulatory policy in place, firms do not know what, if any, future costs they will face for GHG emissions. This uncertainty hinders investments in CCS.

Nearly all individual components of CCS technologies are currently employed on an industrial scale.

Firms face challenges in financing CCS projects both in states with traditional cost-of-service electricity regulation and in states with restructured electricity markets. Given the large incremental costs of CCS and the obligation of public utility commissions (PUCs) to protect ratepayers from excessive costs, a utility in a traditionally regulated state that sought to build a power plant with CCS would likely have difficulty justifying it as a prudent investment given the absence of a regulatory policy requirement or a cost placed on GHG emissions and the risk associated with new technologies that have not been extensively deployed at a commercial scale. For the same reasons, in states with restructured electricity markets, capital markets may be reluctant to provide financing for CCS projects to power producers. Moreover, since society at large will benefit from the valuable information, experience, and cost reductions that initial CCS projects will generate (see discussion below), utility regulators may be reluctant to impose the incremental cost of CCS on the ratepayers in a single state.[33]

Firms also face uncertainty regarding regulations related to CCS. The federal and state governments have not yet established the necessary regulations to govern CO_2 transport and storage, such as site selection, operation, monitoring, closure, long-term care, and liability for CO_2 storage. Faced with uncertainty regarding the regulatory framework and associated cost implications for CO_2 storage, firms are even more reluctant to invest in CCS at this time.

There is also a need for additional CCS RD&D. Nearly all individual components of CCS technologies are currently employed on an industrial scale for purposes ranging from fertilizer manufacturing to EOR.[34] However, to date no commercial-scale coal-fueled power plant employs CCS as an integrated suite of technologies.[35] There exists significant uncertainty regarding the actual cost and performance of carbon capture technology. The first projects to deploy CCS technologies integrated with commercial-scale power plants will generate valuable information on the actual cost and performance of CCS as well as the optimal configuration of the technologies. Initial CCS projects would not only provide hard data on cost and performance, but they would also lead to improvements in the technologies themselves and their integration, and would thus result in cost reductions for CCS.

Emerging energy technologies often experience dramatic cost reductions as they become widely deployed.

Empirical studies find that emerging energy technologies often experience dramatic cost reductions as they become widely deployed, typically estimated as a function of each doubling of installed capacity, as the technologies progress along their "learning curves."[36] The first CCS projects are likely to employ more conservative designs and to encounter unforeseen expenses. Each successive wave of CCS projects will lead to improvements in equipment, configuration, and operation that drive down costs.

Initial commercial-scale CCS projects warrant government funding because the benefits of these projects accrue not just to the projects' developers but to society at large. All firms considering CCS can exploit the information generated by initial CCS projects, not just the owners of the initial projects. As firms learn from their own and others' CCS projects, they can optimize their investments in GHG abatement technologies, and society as a whole benefits from more cost-effective GHG emission reductions.

Putting a Price on Carbon

A federal market-based climate policy, such as a cap-and-trade program, would attach a cost to GHG emissions and thus discourage technologies like traditional coal-fueled power plants without CCS and encourage a wide array of low carbon technologies, including CCS. Market-based policies to address climate change offer several benefits. With a price on carbon, market forces can guide investments in a portfolio of GHG mitigation options. Market-based policies promote innovation which leads to new, lower-cost options for reducing GHG emissions.[37] Finally, a market-based approach promotes the achievement of GHG emission reduction goals at the least cost to society.[38]

The necessary reductions in GHG emissions in the long term will require the deployment of a portfolio of technologies, including CCS, energy efficiency, and renewables; there is no "silver bullet" solution to climate change. Government RD&D incentives for a wide range of technologies would allow competitive forces under a market-based climate policy, such as a cap-and-trade policy, to select the most cost-effective technologies for GHG abatement.

What is the rationale, then, for specific policies to promote CCS? First, financial incentives for CCS do not preclude incentives for other technologies, such as renewable energy. Second, CCS warrants special attention because it is a technology that requires initial commercial-scale projects to prove its viability and to provide much-needed information on costs, performance, and optimal configuration, and these initial projects are very costly. A commercial-scale coal-fueled power plant costs more than $1-2 billion, and the incremental cost of adding CCS is in the many hundreds of millions of dollars.

Market-Based CCS Deployment Incentives

To address obstacles to private-sector investment in CCS, the government could provide financial incentives for CCS deployment. Such incentives could specifically target large-scale projects that deploy CCS coupled with coal-fueled power plants.

One option for providing financial incentives for CCS is to rely on a charge levied on fossil fuel-based electricity to develop a CCS trust fund that would provide financial support for initial commercial-scale CCS projects.[39] If a federal cap-and-trade program is enacted, the government could use allowance value (either in the form of revenue from auctioned allowances or in the form of bonus allowances) to provide financial support for CCS projects.[40] A third alternative for funding CCS projects is to levy fees on new coal plants that do not deploy CCS and to use this money to support new coal plants that do use CCS. See Table 4 for a summary of some recent Congressional proposals related to CCS.

Table 4 *Selected Bills in the 110th Congress Related to CCS*

Bill	Sponsor	Description
H.R. 6258 **The Carbon Capture and Storage Early Deployment Act**	Rep. Boucher (27 Cosponsors)	The bill would authorize utilities to hold a referendum on the establishment of a Carbon Storage Research Corporation, which would collect charges from retail customers of fossil fuel-based electricity (totaling $1 billion annually) and be operated as a division of the Electric Power Research Institute. The Corporation would fund large-scale deployment of CCS in order to accelerate its commercial availability.
S. 3036 **The Lieberman-Warner Climate Security Act of 2008** Substitute Amendment to S. 2191	Sen. Boxer	As part of a cap-and-trade program, the bill would provide funding and incentives for CCS (see Subtitle F). Bill would grant bonus allowances to CCS projects based on avoided emissions where projects would have to meet performance standards to qualify (maximum lbs CO_2 per MWh).
S. 2323 **Carbon Capture and Storage Technology Act of 2007**	Sen. Kerry (2 Cosponsors)	This bill would establish a competitive grant program for commercial-scale CCS demonstration projects. To qualify, power plants would need a nameplate capacity of between 250 and 500 megawatts. The bill would also establish an interagency task force to develop regulations for the CO_2 capture and storage.
H.R. 5575 **Moratorium on Uncontrolled Power Plants Act of 2008**	Rep. Waxman (16 Cosponsors)	This bill would prohibit permitting of new coal-fueled power plants under the Clean Air Act, unless plants use technology to capture and store 85 percent of their CO_2 emissions. Any coal-fueled power plant without CCS built after the bill's introduction would not be eligible to receive free or discounted emission allowances under any future cap-and-trade program.

Source: Pew Center on Global Climate Change, http://www.pewclimate.org/what_s_being_done/in_the_congress/110thcongress.cfm.

Financial incentives for CCS deployment projects could be awarded via competitive bidding in order to ensure the most cost-effective public financial support for CCS projects. For example, the entity tasked with awarding financial incentives for CCS could provide incentives in the form of payments that extend over a certain period (e.g., 10 years) for captured and stored CO_2. Entities seeking financial incentives for CCS projects could submit bids for the rate of subsidy their projects required, and the most cost-effective projects could be awarded financial incentives. Providing incentives for an array of CCS projects that employ different technologies using different fuel types and that store CO_2 in different geologic formations would be in keeping with the need for a portfolio of low carbon technologies.

A 2007 Pew Center report estimated that a government program that paid for the incremental cost of CCS at 10 to 30 commercial-scale coal-fueled power plants plus 5 to 10 CCS projects involving industrial CO_2 sources would cost between $8 and $30 billion depending on the number of projects funded.[41] Such a program could fund both new-build and retrofit CCS projects involving a variety of technologies, coal types, and geologic formations. A program that supported 30 commercial-scale CCS projects would significantly reduce the cost of CCS and enable its widespread deployment.

CCS Research, Development, and Demonstration

In addition to the need for incentives for deployment of large-scale CCS projects described above, there is also a role for continued and expanded government funding for CCS research, development, and demonstration (RD&D). CCS RD&D focuses on technologies that are not yet ready for deployment at a commercial scale. Public funding for CCS RD&D could lead to innovative CCS technologies with lower costs than those currently considered for large-scale deployment.

Geological Storage Demonstration and Capacity Assessment

Continued support and increased funding for large-scale geologic storage projects would enable the characteristics and potential of geologic storage sites and the long-term dynamics of injected CO_2 to be more fully understood. For example, the Energy Independence and Security Act of 2007 (EISA 2007) authorizes $240 million annually for fiscal years 2008-2012 for CO_2 storage RD&D; under these authorizations Congress could fund large-scale CO_2 storage testing. In addition, Congress could direct the U.S. Geological Survey to continue and expand its national assessment of geologic storage capacity and provide increased funding for this effort with some funds designated to support state geologic agencies in their work for the capacity assessment.

CCS R&D could lead to innovative CCS technologies with lower costs than those currently considered for large-scale deployment.

Standards-Based Approaches to Promoting CCS

Technology standards can serve as an alternative to—or complement to—market-based climate policy (such as a cap-and-trade program) and incentives for CCS RD&D. Possible standards-based approaches to promoting CCS are described below.

New Source Performance Standard (NSPS)

Performance standards are a well-known approach to ensuring the environmental performance of power plants as well as other large stationary sources of GHG emissions in the industrial sector. New Source Performance Standards (NSPS) are an important component of the Clean Air Act. Similarly, CO_2 performance standards could also be established, such as a maximum allowable emission rate in terms of CO_2 per unit of output (e.g., metric tons of CO_2 per megawatt-hour). Generally, performance standards are mandatory for units commencing operation after the standards are adopted. In order to achieve the needed level of emission reductions, a performance standard would eventually need to apply not just to new sources but also to the existing fleet of power plants and industrial sources. One way to do this would be to require plants emitting more than a specified amount of CO_2 annually to meet the standard by a certain year or by the time plants have reached a specified age.

A low carbon portfolio standard is analogous to the renewable portfolio standards (RPS) that many states have implemented.

Low Carbon Portfolio Standard

As an alternative to setting performance standards that apply to all power plants individually, one could adopt a low carbon portfolio standard. A low carbon portfolio standard is analogous to the renewable portfolio standards (RPS) that many states have implemented. The advantage of a portfolio standard is that it provides considerably more flexibility to regulated entities than an NSPS. A low carbon portfolio standard would require that electricity generators or retailers produce or sell a certain percentage of electricity that meets a specified low carbon standard (e.g., as expressed in tons of CO_2 per megawatt-hour). As in the case of an RPS, entities required to comply with the low carbon portfolio standard would be allowed to meet the performance standard via their own low carbon generation, purchases of credits from entities who over-comply with the standard, or some combination of the two. Such trading allows for entities to meet the low carbon portfolio standard at the least cost. Implementation of both a low carbon portfolio standard and a cap-and-trade program does not require or benefit from making cap-and-trade allowances and low carbon portfolio standard credits fungible.

The primary options for setting a low carbon portfolio standard are:

- A standard could apply only to coal-fueled units, to all fossil-fuel based units, or to all electricity generation.

- The obligation to meet the standard can be placed either on electricity generators or on retailers. In some cases these are the same entities, but in other cases they are not.
- Either a specified percentage of electricity (in whatever category the standard applies to) has to meet a specified CO_2 emission rate, or all electricity (in the category) has to meet the standard. In the former case, the emission rate is stringent but the percentage of electricity having to meet it starts low and increases over time. Under the second option, the standard starts near current emission rates and decreases over time.

A Regulatory Framework to Enable Carbon Storage

Although injection of CO_2 for enhanced recovery of oil and gas is regulated under the U.S. Environmental Protection Agency's (EPA) Underground Injection Control (UIC) program, there are material differences between those regulations and regulations that would be appropriate for very long-term geologic storage of CO_2. As DOE is engaging in geologic storage tests, EPA has provided rules to cover pilot CO_2 storage projects and has proposed rules for large-scale commercial geologic storage projects under the UIC.[42] If CCS is widely deployed, the volume of CO_2 stored in geologic formations will be similar to the total volume of all other injectants currently regulated under the UIC program. However, individual sources of CO_2 will be larger than for other injectants while CO_2, unlike most other injected substances, is buoyant when first injected.[43] EPA's proposed regulations for geologic storage of CO_2 are based on EPA's authority to protect underground drinking water supplies; however, geologic storage of CO_2 may pose risks beyond groundwater damage.

CO_2 storage regulations should provide firms with predictability while also being adaptable.

Regulations governing CO_2 storage should provide the predictability that project developers need to move CCS projects forward while also being flexible in order to adapt to what regulators learn from the initial large-scale storage projects; one way to develop regulations for geologic storage is to take a two-phased approach.[44] In the first

Box 3 *What Keeps CO_2 Underground?*

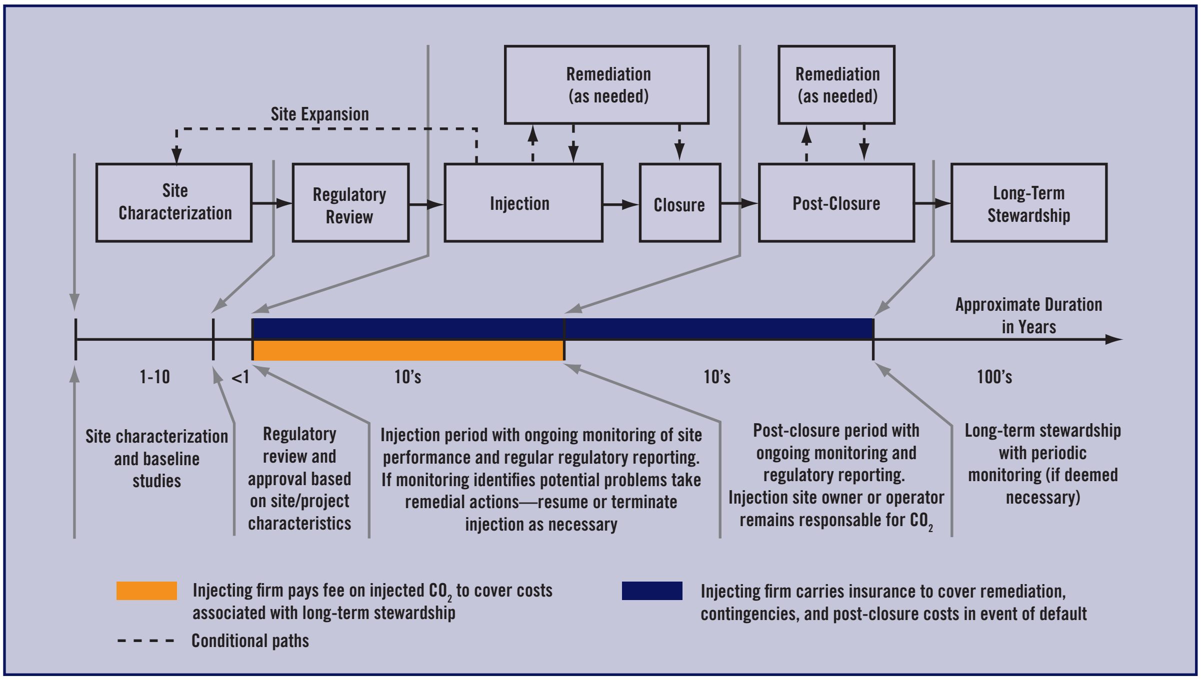
Suitable sites for geologic storage of CO_2 in deep saline formations have deeply buried (e.g., greater than 1 kilometer) permeable rock formations with impermeable layers of caprock above them. Geologic CO_2 storage requires drilling down to the permeable rock layers and injecting the CO_2. The permeable rock layer into which CO_2 is injected consists of grains of rock infused with salt water that is not suitable for drinking or irrigation. Injected CO_2 moves into the spaces between the rock grains in the permeable layer. Initially, the impermeable caprock traps the injected CO_2 in the permeable layer. Secondary trapping mechanisms also act to keep CO_2 underground. CO_2 dissolves in the saline water and is trapped by intermolecular forces between the CO_2 and the surrounding rock (capillary forces), and over time some of the CO_2 converts to solid minerals.

Source: Benson, Sally, *Potential Liabilities and Mitigation Strategies for CCS*, WRI CCS Long-Term Liability Workshop, June 2007.

phase, initial projects would be governed under existing regulations with special provisions as needed. The initial projects would provide information on the risk profile of actual, large-scale geologic storage operations which can inform the development of comprehensive regulation in the second phase. CCS regulations could cover: site selection; well, injection, and closure operations; and long-term monitoring and verification (see Figure 2). Geological storage regulations might apply to EOR projects only if the EOR projects seek credit for CO_2 storage (e.g., in the form of allowances awarded under a cap-and-trade program). Three prominent efforts to develop recommendations for comprehensive CO_2 transport and storage regulations are those of the Interstate Oil and Gas Compact Commission (IOGCC), the World Resources Institute (WRI), and the CCSReg Project.[45]

The private market may fail to provide insurance for long-term liability for geologic storage projects since such liability effectively extends into the far distant future (i.e., centuries). Firms may not invest in large-scale, commercial CCS projects if private insurers cannot offer long-term liability insurance for geologic storage projects. As such, the federal government may have a role to play in assuming long-term liability for stored CO_2. For example, in keeping with the two-phase approach to regulating CCS, the government could make special provisions for long-term liability for initial large-scale CCS projects. Initial projects that receive the benefit of these special provisions could be required to provide transparent data to help better understand the risk profile, cost, and performance of geologic storage.

Figure 2 *Possible CCS Liability Framework*



Source: Rubin et al., May 2007.

In the second phase of regulatory development, the government could establish an entity (e.g., a CO_2 storage fund) that would take over long-term liability and stewardship responsibility from geologic storage project owners. Regulations for CO_2 storage could specify the requirements that entities must meet to turn over storage sites to the government for long-term stewardship. A charge levied on each ton of stored CO_2 could feed into the CO_2 storage fund, where fees could be tailored to the risk profile of each geologic storage project. If a public entity such as a CO_2 storage fund is created, care should be taken to avoid creating perverse incentives by shifting risk from the private to the public sector.

A cap-and-trade program would need provisions for how to treat any long-term leakage of CO_2 from geologic storage sites. One option is to have geologic storage operators prospectively surrender allowances for any predicted CO_2 leakage prior to turning over the site for long-term stewardship. An alternative is to have the CO_2 storage fund buy allowances to match measured CO_2 leakage from sites under its stewardship.

Checklist of Key Design Questions for Policymakers

- What incentives would be sufficient to spur private sector investment in commercial-scale CCS projects and how should these incentives be designed?
- Which policies could lead to a large enough number of initial CCS projects to provide the real-world cost and performance information and cost savings from technology improvements necessary for widespread CCS deployment?
- Are such policies designed in a way to support a portfolio of CCS technologies and configurations?
- Is a performance standard necessary to promote the use of CCS and, if so, should the standard be generator-based or portfolio-based?
- What gaps exist in current regulations governing CO_2 transport and storage? What are the roles of relevant federal and state authorities?
- How is the issue of long-term liability for CO_2 storage handled?
- What is the best way to encourage CCS deployment in developing nations that also rely heavily on coal for electricity generation?

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