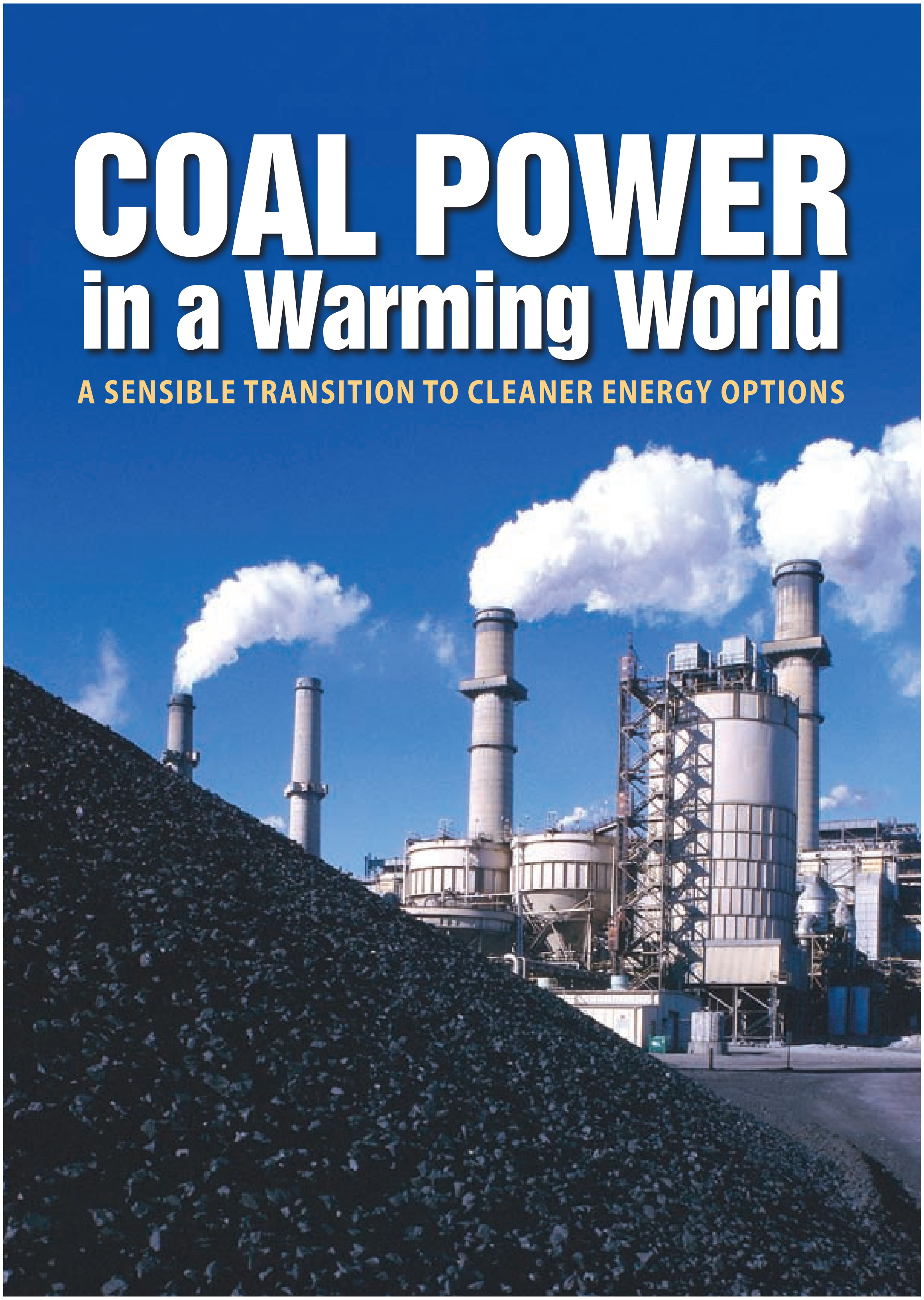

COAL POWER in a Warming World

A SENSIBLE TRANSITION TO CLEANER ENERGY OPTIONS

Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

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in a Warming World

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OCTOBER 2008

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The Union of Concerned Scientists is the leading science-based nonprofit working for a healthy environment and a safer world.

The UCS Clean Energy Program examines the benefits and costs of the country's energy use and promotes energy solutions that are sustainable both environmentally and economically.

More information about the Union of Concerned Scientists and the Clean Energy Program is available on the UCS website at *www.ucsusa.org*.

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Executive Summary

If the United States continues burning coal the way it does today, it will be impossible to achieve the reductions in heat-trapping emissions needed to prevent dangerous levels of global warming. Coal-fired power plants represent the nation's largest source of carbon dioxide (CO_2, the main heat-trapping gas causing climate change), and coal plant emissions must be cut substantially if we are to have a reasonable chance of avoiding the worst consequences of climate change.

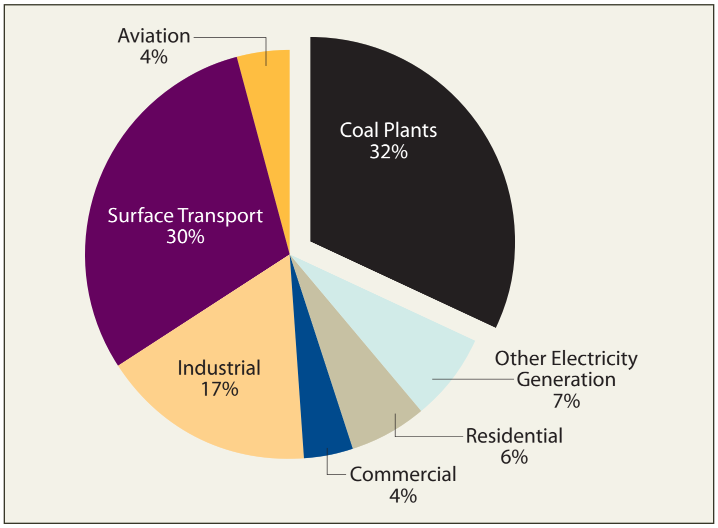
TREADING A DANGEROUS PATH

Yet despite the urgent need to reduce CO_2 emissions, the United States is poised to *increase* its emissions greatly—by building many more coal plants. Virtually all of these new plants, like existing ones, would lack so-called carbon capture and storage (CCS) technology—equipment that would allow a plant to capture CO_2 before it is released and then store it underground.

CCS is still an emerging technology. It has the potential to substantially reduce CO_2 emissions from coal plants, but it also faces many challenges. In its current form the technology would greatly increase the cost of building and running coal plants while greatly reducing their power output. In addition, careful selection and monitoring of geologic storage (or "sequestration") sites, and the development of regulatory standards and mechanisms to guide this process, will be needed to minimize the environmental risks associated with CO_2 leakage (including groundwater contamination).

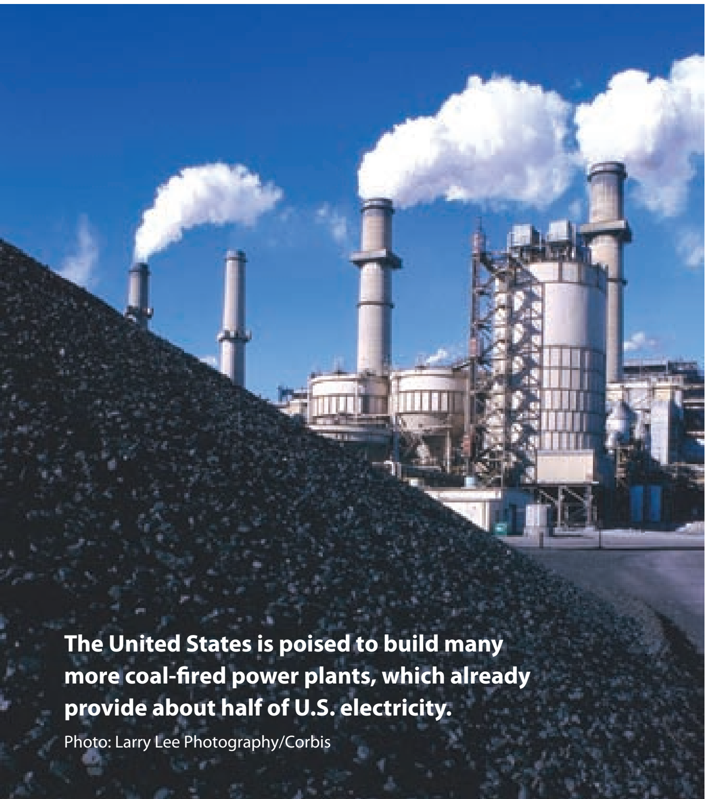
For CCS to play a major role in reducing CO_2 emissions, an enormous new infrastructure must be constructed to capture, process, and transport large quantities of CO_2. And although CCS has been the subject of considerable research and analysis, it has yet to be demonstrated in the form of commercial-scale, fully integrated projects at coal-fired power plants. Such demonstration projects are needed to determine the relative cost-effectiveness of CCS compared with other carbon-reducing strategies, and to assess its environmental safety—particularly at the very large scale

FIGURE 1: **U.S. CO_2 Emissions by Source, 2006**



Coal-fired power plants emit more CO_2—about one-third of the U.S. total—than any other source, including surface transportation.

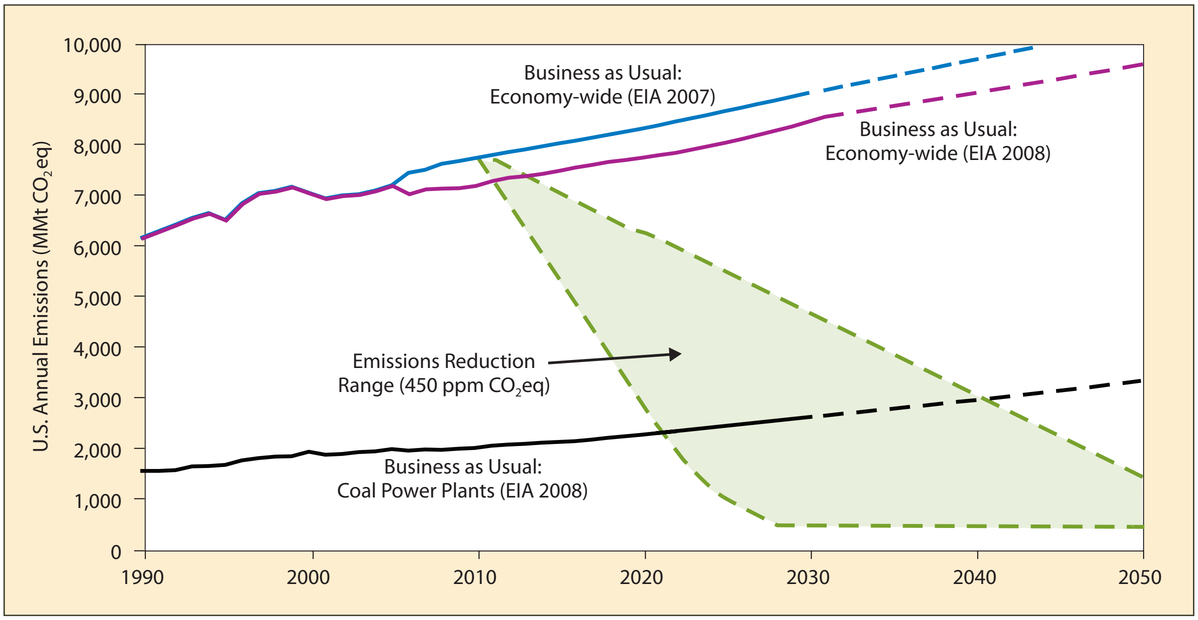
Source: Energy Information Administration (EIA). 2008. *Annual energy outlook 2008*. And: EIA. 2007. *Emission of greenhouse gases in the United States 2006.*



The United States is poised to build many more coal-fired power plants, which already provide about half of U.S. electricity.

Photo: Larry Lee Photography/Corbis

FIGURE 2: Rising Coal Emissions Compared with Needed U.S. Economy-wide Emissions Reductions by 2050



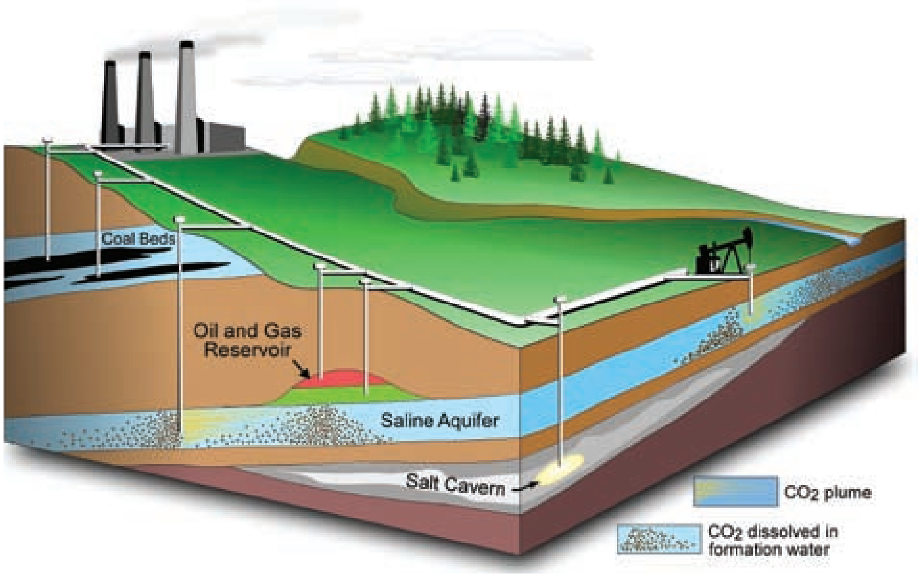
If CO_2 emissions from coal-fired power plants continue to rise at rates projected by the U.S. Energy Information Administration, it will be impossible for the United States to achieve the steep economy-wide emissions reductions it needs to have a reasonable chance of avoiding the worst effects of climate change. In fact, projected emissions from coal plants alone could exceed the level of total global warming emissions we can afford for the entire economy—including the transportation, residential, commercial, industrial, and agricultural sectors—between 2020 and 2040. The United States would need to reduce its total emissions at least 80 percent below 2000 levels by 2050 to achieve the range of reductions shown in the figure.

Source: Luers et al. 2007. *How to avoid dangerous climate change: A target for U.S. emissions reductions.* Projected emissions through 2030 from EIA, *Annual energy outlook 2007* and *Annual energy outlook 2008*, Reference case, extrapolated to 2050 by UCS. EIA emissions projections are lower in EIA 2008, largely because of the December 2007 passage of the Energy Independence and Security Act.

Mountaintop removal mining in Appalachia permanently destroys mountains and valleys, threatening the culture and biodiversity of the region. This photo, taken in December 2005, shows a mining operation located near Marthatown, WV.

Photo: Vivian Stockman, Ohio Environmental Coalition (ohvec.org)

FIGURE 3: Geologic Sequestration of CO_2



Carbon capture and storage (CCS) technology would allow the CO_2 from coal-fired power plants to be captured and injected into geologic formations such as depleted oil and gas reservoirs, unmineable coal seams, or saline aquifers. No coal-fired power plants currently employ this technology, but several commercial-scale demonstration projects have been announced around the world.

Source: Alberta Geological Survey.

of deployment needed for CCS to contribute significantly to the fight against global warming.

Already, the United States gets about half of its electricity from coal plants that lack CCS. Building more coal plants without CCS would not only increase the risk of irreversible and dangerous climate change but also increase our nation's dependence on a fuel whose mining and use cause other environmental damages, human health problems, and deadly accidents. Furthermore, an expansion of our coal fleet could inhibit the development of inherently cleaner, safer, and more sustainable technologies such as energy efficiency and renewable power (e.g., wind, solar).

The coal industry is even planning to develop new markets for coal in the form of liquid and gas fuels for transportation and other purposes. "Liquid coal" would increase net CO_2 emissions even if the conversion process employed CCS technology, and would greatly increase CO_2 emissions without it. Coal-to-gas technology could either increase CO_2 emissions or decrease them depending on whether it displaces other uses of coal.

THE WAY TO A CLEANER, SAFER FUTURE

Given the critical importance of combating climate change, all coal-related investments and policies should be judged by the ultimate standard of whether they will reduce global warming pollution at the pace and on the scale needed to avoid the worst consequences of climate change. Other considerations should include the environmental, human health and safety, and socioeconomic impacts of such investments and policies.

With these standards in mind, the United States should:

- ***Increase research and development (R&D) for CCS*** to evaluate the technology's potential in the fastest way possible. The United States should fund 5 to 10 full-scale, integrated CCS demonstration projects at coal-fired power plants, using different types of generation and capture technologies and different types of sequestration sites. Investing in demonstration projects is warranted given the promise this technology holds and is needed to determine whether wider deployment is appropriate, but it is premature to provide incentives for widespread deployment.

  These demonstration projects (and a detailed survey of possible sequestration sites) should be funded initially by a modest fee paid by operators of existing coal plants and later by a small portion of the revenue generated by auctions of pollution allowances under a cap-and-trade program. Support should be focused on CCS demonstration projects that actually reduce emissions from existing coal plants. In addition, the demonstration program should include the development of regulatory protocols for selecting and monitoring sequestration sites. As the technology becomes proven at commercial scale, it should be eligible to compete against other carbon-reducing technologies for funds intended to accelerate deployment.

- ***Stop building new coal-fired power plants without CCS.*** Each new coal plant built without CCS represents a major long-term source of CO_2. It is not safe to assume that new coal plants built today without CCS could cost-effectively add it later, because the cost of CCS (considerable even when included in the plant's original design) would be much higher if added as a retrofit. The federal government should therefore adopt a strong performance standard limiting CO_2 emissions from new coal plants, which will prevent the construction of any plant not employing CCS from the outset. Until such a policy is put in place, state regulators should evaluate proposed plants using a projected range of prices those plants would likely have to pay for their CO_2 emissions under a cap-and-trade program.
- ***Stop investing in new coal-to-liquid plants and reject policies that support such investments.*** Coal-to-liquid technology cannot reduce CO_2 emissions (compared with petroleum-based fuels), but it could greatly increase those emissions. It should not, therefore, have any part in our energy future. All transportation fuels should be held to a low-carbon performance standard that limits global warming pollution and provides safeguards against other environmental damage.
- ***Ensure that any coal-to-gas plants employ CCS and that the resulting fuel is used to offset coal use rather than natural gas use.*** Because coal-to-gas plants could either help or hinder our efforts to fight global warming, regulations are needed to ensure that this technology leads to CO_2 reductions, not increases.
- ***Significantly increase both deployment of and R&D for energy efficiency and renewable energy.*** States and the federal government should adopt policies such as renewable electricity standards, energy efficiency programs, and appliance efficiency standards that would accelerate the deployment of energy efficiency and renewable energy technologies. The federal government should also greatly expand its R&D and demonstration funding for these technologies (including energy storage technologies). Federal research money has long focused disproportionately on coal and nuclear power, greatly underfunding inherently cleaner technologies despite their tremendous potential. Given the urgency of the threat posed by global warming, this underfunding must be corrected.

  In combination, these deployment and R&D investments in energy efficiency and renewable energy will minimize the near-term cost of reducing carbon emissions, buy time until the cost-effectiveness of CCS can be demonstrated at commercial scale, ensure a diverse set of long-term low-carbon options, and avoid perpetuating the undue advantage coal has long had over cleaner energy technologies.
- ***Adopt statutes and stronger regulations that will reduce the environmental and societal costs of coal use*** throughout the fuel cycle. Our use of coal, from mining through waste disposal, has serious impacts on the safety and health of both humans and our environment. Policies are needed to reduce these impacts and place coal on a more level playing field with low-carbon alternatives. This would include a ban on mountaintop removal mining and tougher standards for mercury emissions, mine safety, and waste disposal. Any federal policy that promotes coal use, including ongoing or expanded CCS subsidies, must be accompanied by such measures.
- ***Put a price on CO_2 emissions by adopting a strong economy-wide cap-and-trade program*** that, in concert with other policies, will drive emissions reductions from existing coal plants and help ensure that the price of coal reflects its true costs. The revenues generated by the auction of pollution allowances under this cap-and-trade program should be used to 1) augment deployment of the most cost-effective low-carbon technologies and 2) provide assistance to communities and workers affected by any coal plant or mine closures.
- ***Ensure the transfer of low-carbon technologies to other countries***—especially developing countries such as China and India—to reduce the serious threat posed by the world's expanding use of coal without CCS. The United States should also provide financing for the international deployment of low-carbon technologies such as integrated gasification combined cycle (IGCC) and CCS (where such technologies are cost-effective relative to other low-carbon alternatives).

CHAPTER ONE

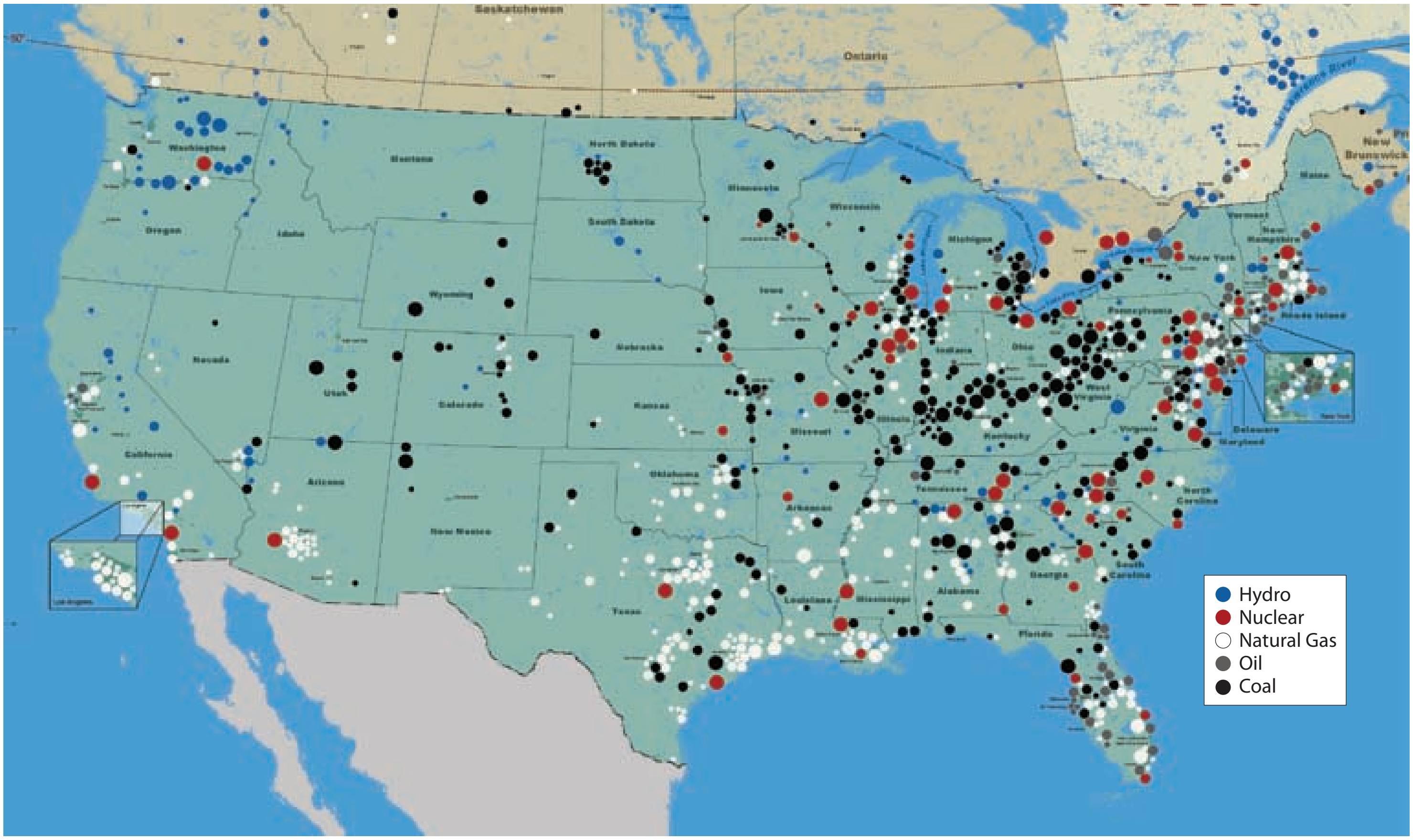
Introduction

Coal, a sedimentary organic rock with a high concentration of carbon (between 40 and 90 percent by weight), is the most widely used fuel for generating electricity in both the United States and the world. It has the advantages of being relatively abundant and widely distributed. While total U.S. coal reserves are difficult to estimate, it is probable that this country has at least a 100-year supply at today's consumption levels[1]—far more than our domestic supplies of oil and natural gas.

While coal-fired power plants cost more to build than plants that burn other fossil fuels, the traditionally low cost of coal has made it relatively inexpensive and profitable for utilities to continue operating the 500 or so existing coal plants that currently supply about half of the nation's electricity.[2] The Merrimac coal plant in New Hampshire, for example, earned an implied rate of return of 67 percent in 2005, according to a utility calculation.[3]

Coal contributes significantly to the economies of a number of communities and states, through jobs and revenue from mining and power plant operations. More than 80,000 people were employed by coal mines in 2006,[4] and thousands more in coal-fired power plants. Coal is currently mined in 26 states,

FIGURE 4: U.S. Power Plants by Fuel Type



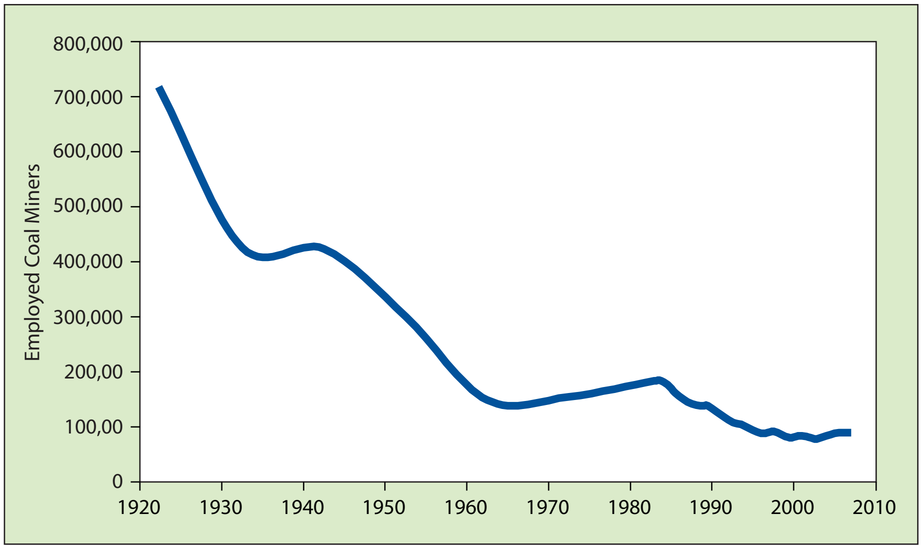
There are more than 500 coal-fired power plants in the United States (only plants over 200 MW are shown here).

Source: Hydro-Québec. No date. Online at *http://www.hydroquebec.com/sustainable-development/documentation/pdf/autres/carte_emissions.pdf*. Accessed August 28, 2008.

FIGURE 5: U.S. Coal Mining Employment

Jobs in the U.S. coal mining industry have declined from more than 700,000 in the early 1920s to approximately 83,000 in 2007.

Source: National Mining Association. 2007. Trends in U.S. Coal Mining, 1923–2007.



Supplying the nation's coal-fired power plants for a single year requires the equivalent of a 104,000-mile-long train—long enough to circle Earth more than four times. Photo: PictureQuest

though 62 percent of the coal used in the United States in 2006 came from just three states: Kentucky, West Virginia, and Wyoming.[5]

A LONG LIST OF DISADVANTAGES

Coal's advantages must be weighed against its many disadvantages:

- The underground mining of coal is a dangerous profession, and underground and surface mining are both highly damaging to landscapes, water supplies, and ecosystems.
- About 40 percent of U.S. railroad freight traffic is devoted to the transport of coal. Viewed another way, fueling our coal-fired power plants for a single year requires the equivalent of a 104,000-mile-long train—long enough to circle the earth more than four times.
- The burning of coal releases more than 100 pollutants into the atmosphere. It is the largest source of sulfur dioxide emissions (which cause acid rain), the second largest source of nitrogen oxides (which contribute to smog and asthma attacks), and the largest source of fine soot particles (which contribute to thousands of premature deaths from heart and lung disease yearly).[6] Coal plants are also the largest remaining source of human-generated mercury, which contaminates lakes and streams, the fish that live in them, and anyone who eats those fish.[7]
- Cooling and scrubbing coal plants requires copious volumes of water. Power plants in general are responsible for approximately 39 percent of U.S. freshwater withdrawals, second only to agricultural

irrigation.[8] While most of that water is returned to the source, the act of withdrawal kills fish, insect larvae, and other organisms, and aquatic ecosystems are further damaged by the return of water that is both hotter than when it was withdrawn and contains chlorine or biocides added to protect plant operations.[9]

- Mountaintop removal mining in Appalachia permanently destroys mountains and adjacent valleys, has destroyed hundreds of thousands of acres of forests, and has buried more than 700 miles of some of the most biologically diverse streams in the country.[10]
- Coal mining and combustion both create wastes that must be disposed. Combustion results in more than 120 million tons of fly ash, bottom ash, boiler slag, and sludge from air pollution controls annually—roughly the same amount as all municipal solid waste disposed in U.S. landfills each year.[11] Though uses have been found for some of this material, most of it goes into landfills and surface impoundments, from which mercury, lead, cadmium, arsenic, and other toxic constituents of this waste can leak out and contaminate water supplies.[12] Mining wastes, particularly in the hundreds of coal slurry impoundments in Appalachia, also pose serious environmental threats.
- Most importantly, coal is the most carbon-intensive fuel. Even newer coal plants produce more than two times the CO_2 emissions of a new natural gas combined cycle plant and over 50 percent more than the CO_2 emissions of generating electricity with oil.[13] CO_2 emissions are the predominant human contribution to global warming, and coal plants represent the single biggest source (about one-third) of the U.S. share of these emissions—about the same as all of our cars, trucks, buses, trains, planes, and boats combined.[14] The final third of U.S. CO_2 emissions come from fossil fuels used in natural gas- and oil-fired power plants, industry, businesses, and residences.

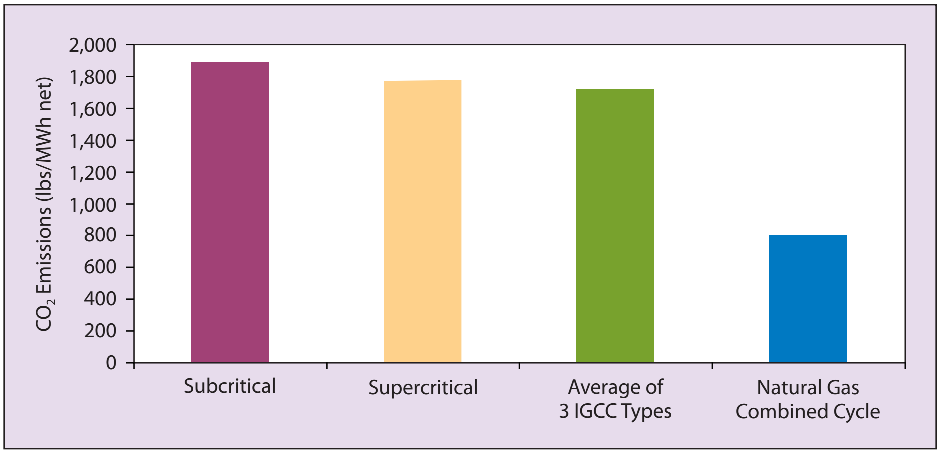
COAL'S ROLE IN THE CLIMATE CRISIS

Global warming poses a profound threat to humanity and the natural world, and is one of the most serious challenges humankind has ever faced. The atmospheric concentration of CO_2 has reached levels the planet has not experienced for hundreds of thousands of years, and the global mean temperature has been rising steadily for more than a century as a result. The Intergovernmental Panel on Climate Change (IPCC)

Every year, air pollution from existing coal-fired power plants—many of which still do not employ modern pollution controls—causes hundreds of thousands of asthma attacks and contributes to thousands of premature deaths from heart and lung disease. Photo: James Estrin/The New Times/Redux

Coal mining wastes accumulate in hundreds of impoundments (or so-called slurry ponds) in Appalachia. In 2000, 300 million gallons of waste escaped from an impoundment in Inez, KY, and flowed into the Big Sandy River, killing 1.6 million fish and contaminating the water supplies of 27,000 people. Photo: Paul Corbit Brown

FIGURE 6: CO$_2$ Emissions from Coal- and Gas-fired Power Plants



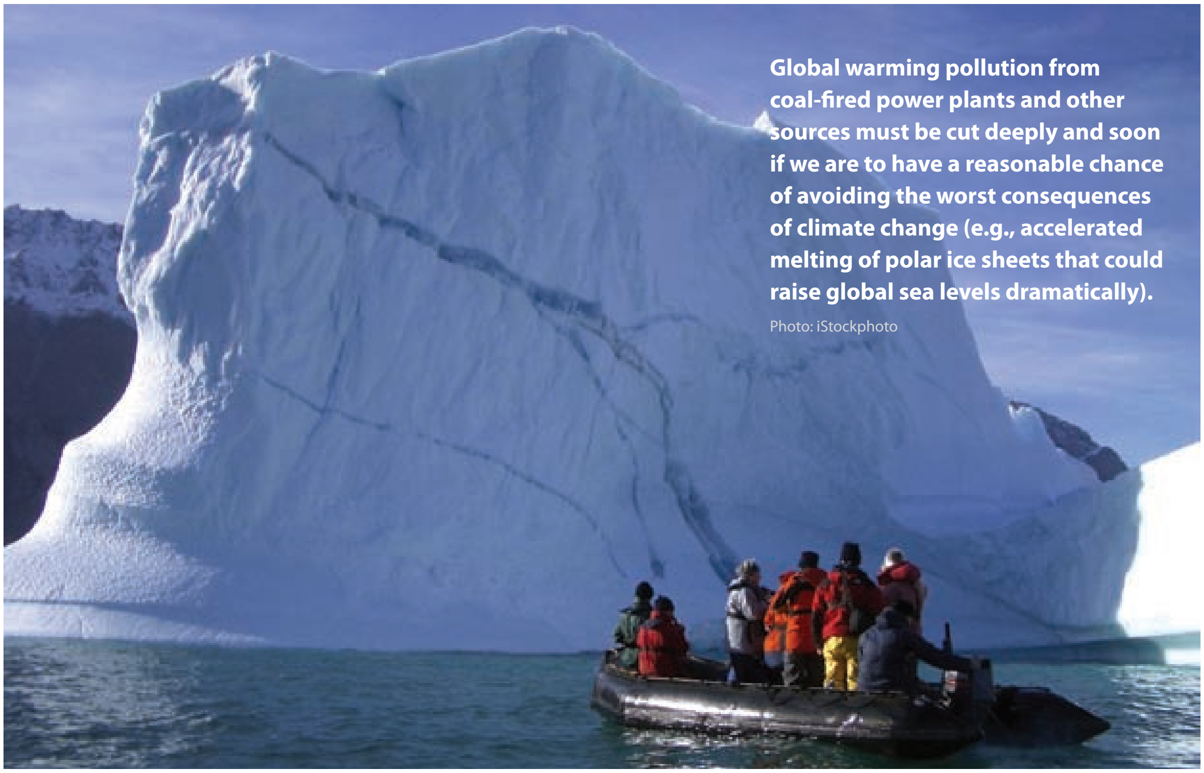
Coal plants—even the newest and most efficient—emit more than twice as much CO$_2$ per megawatt-hour as new natural gas plants.

Source: National Energy Technology Laboratory. 2007. *Cost and performance baseline for fossil energy plants.*

and scientific academies around the world (including the U.S. National Academy of Sciences) have all stated that human activity, especially the burning of fossil fuels, is a major driver of this warming trend.

The window for holding global warming pollution to reasonably safe levels is closing quickly. For the world to have a reasonable chance of avoiding the worst consequences of global warming, the United States must cut its heat-trapping emissions at least 80 percent below 2000 levels by 2050.[15] This requirement assumes that our emissions peak in 2010 and then immediately begin to decline. If emissions keep rising beyond 2010, we will need to make even deeper cuts.

Remarkably, despite the urgent need to reduce CO$_2$ emissions from coal plants, the nation is currently making major long-term investments in new coal plants that will greatly *increase* CO$_2$ emissions. After a couple of decades in which almost no new coal plants were built, utilities around the nation are proposing to build more than 100 such plants. The U.S. Department of Energy (DOE), which has been tracking coal plant announcements and periodically reporting on their status, estimated in February 2008 that 47



Global warming pollution from coal-fired power plants and other sources must be cut deeply and soon if we are to have a reasonable chance of avoiding the worst consequences of climate change (e.g., accelerated melting of polar ice sheets that could raise global sea levels dramatically).

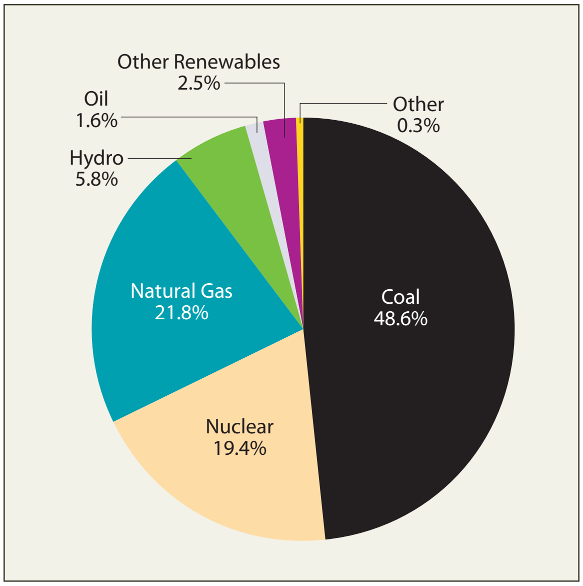
Photo: iStockphoto

coal plant proposals were "progressing" (meaning the plants were under construction, near construction, or in the permitting phase).[16] Another 67 have been announced. Altogether, these 114 proposed plants would represent a 20 percent increase in the size of our coal fleet, substantially expanding the nation's dependence on the resource that already dominates our electricity mix and has the most adverse environmental impact.[17]

The impact of these new plants on global warming pollution specifically would be enormous. If only half were built, they would emit as much CO_2 in a year as 39 million cars, and would continue to do so for decades.[18] Even worse, the DOE has projected that 167 coal plants would be built under a business-as-usual scenario (i.e., one that does not include any policies to reduce global warming emissions), which would result in a 33 percent increase in coal plant CO_2 emissions over current levels by 2030.[19] Such a scenario would make it impossible to achieve the steep, economy-wide emissions reductions we need (see Figure 2, p. 2).[20]

Additionally, the coal industry has visions of converting coal into both a liquid (as a substitute for diesel and gasoline in transportation) and a gas (as a substitute for natural gas). Peabody Coal, the nation's largest coal producer, recently told financial analysts that it expects U.S. coal consumption to nearly triple from its current level of 1 billion tons per year by 2030. New power plants would comprise about 500 million tons or more of the additional consumption,

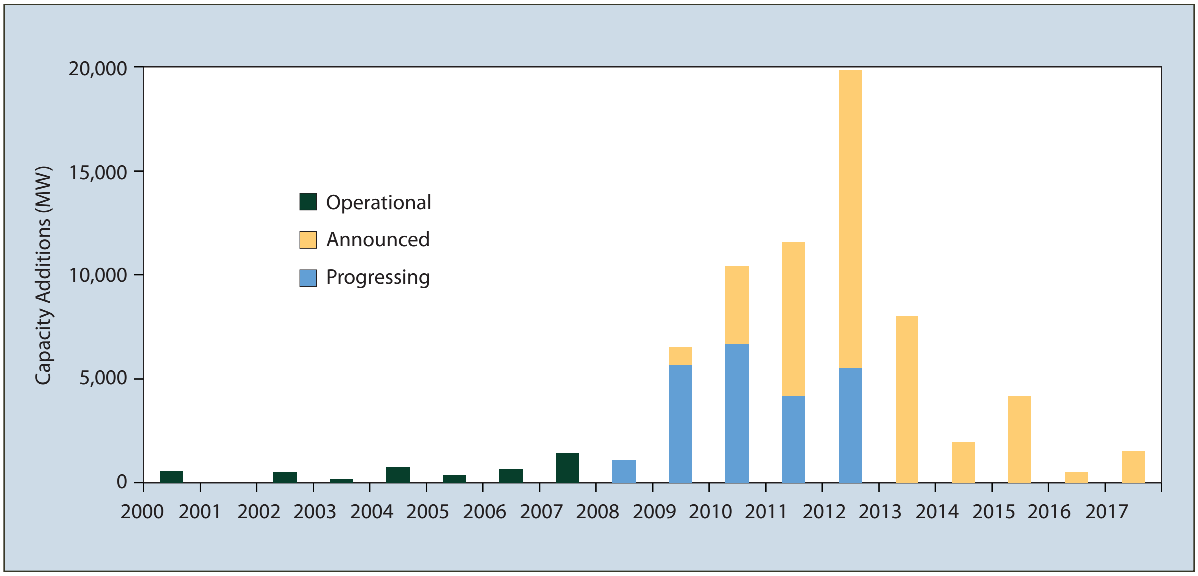
FIGURE 7: **U.S. Electricity Generation by Source, 2007**



The United States obtains more electricity from coal-fired power plants than from any other generation technology.

Source: Energy Information Administration. 2008. Electric power monthly. August 25.

FIGURE 8: **Status of Proposed U.S. Coal-fired Power Plants**



Progress on more than 114 proposals for new coal plants—representing more than 65,000 megawatts (MW) of new capacity—is tracked by the U.S. Department of Energy.

Source: National Energy Technology Laboratory.

with coal-to-gas contributing 340 million tons and liquid coal another 1 billion tons.[21]

WHAT IS COAL'S FUTURE ROLE?

In the months since the number of proposed coal plants tracked by the DOE peaked at 151 in May 2007, a growing number of cancellations have been announced. In 2007, regulators rejected plants in Florida, Kansas, North Carolina, Oklahoma, and Oregon. Eight of 11 proposed plants were cancelled in an investor buyout of TXU in Texas, and another eight were cancelled or defeated in Illinois. In total, about 60 proposals were cancelled or defeated in 27 states in 2007.[22]

There are many technologies available to meet our growing energy needs without building more conventional coal plants. In addition to technologies for increasing energy efficiency, harnessing renewable energy resources such as the wind and sun, and improving the safety and security of nuclear power plants, advanced coal technologies not yet in use may provide an opportunity for our coal reserves to continue playing a role in the nation's energy future.

This report examines the prospects and challenges facing these emerging coal technologies. We also offer recommendations for ensuring such technologies have a fair opportunity to compete for market share, while not jeopardizing our ultimate transition to resources that may be less expensive and pose fewer environmental and health risks.

> **"The only practical way to prevent CO_2 levels from going far into the dangerous range, with disastrous effects for humanity and other inhabitants of the planet, is to phase out use of coal except at power plants where the CO_2 is captured and sequestered."**
>
> — *Dr. James Hansen, director of NASA's Goddard Institute for Space Studies (written testimony submitted to the Iowa Utilities Board, November 5, 2007)*

CHAPTER TWO

Advanced Coal Technologies Hold Promise but Face Many Challenges

At the moment, there is no commercially available control technology that can be added to existing coal-fired power plants in order to reduce their CO_2 emissions in the way that scrubbers and baghouses can be installed to capture sulfur dioxide and particulate emissions, respectively. However, carbon capture and storage (CCS) is an emerging technology that, especially when combined with advanced combustion technology, would allow plant operators to capture CO_2, transport it to a "geologic sequestration" site, and pump it into the ground, where it would ideally remain safely stored over the very long term.

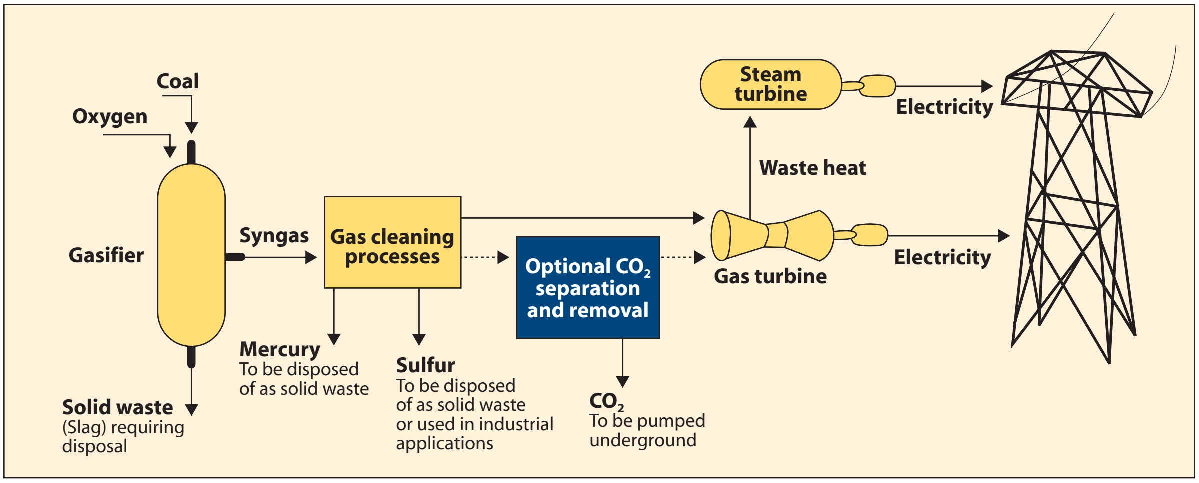
This process has not yet been employed on a commercial scale at any power plant, though as we discuss below and in Appendix A, several projects that would employ commercial-scale CCS at power plants are under development.[23] Most of the component technologies are already being used commercially in other industrial applications.

An important potential benefit of developing CCS technology is that it may someday be applied to power plants that burn or gasify biomass (plant-based materials). Such a power plant could actually be carbon-negative because the plant matter comprising the biomass will have taken CO_2 from the air through the process of photosynthesis, and CCS technology will then capture the CO_2 and store it underground. Having the ability to achieve negative CO_2 emissions in future decades may well be needed if we are to keep global CO_2 concentrations at relatively safe levels.

IGCC FACILITATES CARBON CAPTURE

Almost all coal plants operating today use "pulverized coal" technology, which involves grinding the coal, burning it to make steam, and using the steam to generate electricity. A newer technology known as integrated gasification combined cycle (IGCC) converts coal into a gas, runs the gas through a combustion turbine to generate electricity, and uses the excess heat from that process to generate additional

FIGURE 9: Inside an IGCC Power Plant



Integrated gasification combined cycle (IGCC) technology heats coal under pressure to form "syngas." This gas is refined by removing mercury and sulfur; additional equipment could be added to separate and remove the CO_2 as well. A gas turbine and a steam turbine (powered by waste heat from the gas turbine) both generate electricity.

Source: Environmental Protection Agency (EPA). 2006. *Environmental footprints and costs of coal-based integrated gasification combined cycle and pulverized coal technologies.*

There are two IGCC plants currently operating in the United States; the 260 MW unit shown here is located at the Polk Power Station near Tampa, FL.

Photo: Teco Energy

electricity via a steam turbine (hence the term "combined cycle").

There are only four coal-fired IGCC plants operating in the world, two in the United States and two in Europe. Of the 114 proposed coal plants cited above, 32 would use IGCC technology rather than traditional pulverized coal technology.[24] However, some of these 32 plants are among the 17 announced IGCC plants that have been cancelled,[25] and as of mid-2008 only one such plant, in Indiana, was actively under construction.[26] In Ohio, construction that began in 2005 on a new IGCC plant to be fueled by petroleum coke (or "petcoke," a solid by-product of petroleum refining very similar to coal) was subsequently halted, reportedly for financial reasons; legal challenges over its air permit may prevent construction from recommencing.[27] And construction on a Florida IGCC plant to be fueled by coal and backed by a federal loan guarantee was suddenly cancelled just two months after its September 2007 groundbreaking. The plant's utility backers cited the growing likelihood that future limits on CO_2 emissions would increase operational costs.[28]

Recent market developments have made IGCC technology more commercially available. Proponents of the technology note that three large corporations—GE, Mitsubishi, and Siemens—now offer all of the major IGCC components in a single package, reducing the risk to power companies.[29] However, as noted above, several commercial-scale IGCC projects have been cancelled or face an uncertain future, raising questions about whether the technology is in fact commercially viable (at least under current climate policies).

IGCC technology is currently more expensive than pulverized coal technology, but it has certain environmental advantages. While modern pollution controls for nitrogen oxides, sulfur dioxide, and particulate matter can dramatically reduce emissions from pulverized coal plants (by 90 to 99 percent), IGCC plants are capable of even greater reductions. It is also easier and less costly to capture and dispose of mercury from an IGCC plant than from a pulverized coal plant, which will be increasingly important as mercury restrictions come into effect in the years ahead. Additionally, while IGCC plants still use a great deal of water, they use 20 to 35 percent less than pulverized coal plants.[30]

The most important environmental advantage IGCC has over pulverized coal is that it is more amenable to carbon capture. The gasification process allows for the separation and capture of CO_2 prior to combustion, when it is still in a relatively concentrated and pressurized form (see Appendix A). Pulverized coal plants can only capture CO_2 after combustion, when it is far more diluted and harder to separate. So while carbon capture technology adds greatly to the cost of an IGCC plant (discussed in more detail below), it costs even more to add it to a pulverized coal plant.

Pre- and post-combustion technologies are both expected to capture between 85 and 95 percent of a plant's CO_2, but when factoring in the additional fuel used just to power the CO_2 removal process, the actual amount of CO_2 avoided per unit of electricity falls to the 80 to 90 percent range.[31] Importantly, IGCC plants without carbon capture technology will emit about as much CO_2 as the most efficient new pulverized coal plants.[32]

None of the 32 proposed IGCC plants identified by the federal government includes carbon capture technology.[33] Two additional projects that would include carbon capture are not on the government's list: a proposed coal-fired IGCC plant in Washington State and a proposed petcoke-fired IGCC plant in California (see Appendix A). Other IGCC projects with CCS have been announced in Australia, China, and Europe.[34]

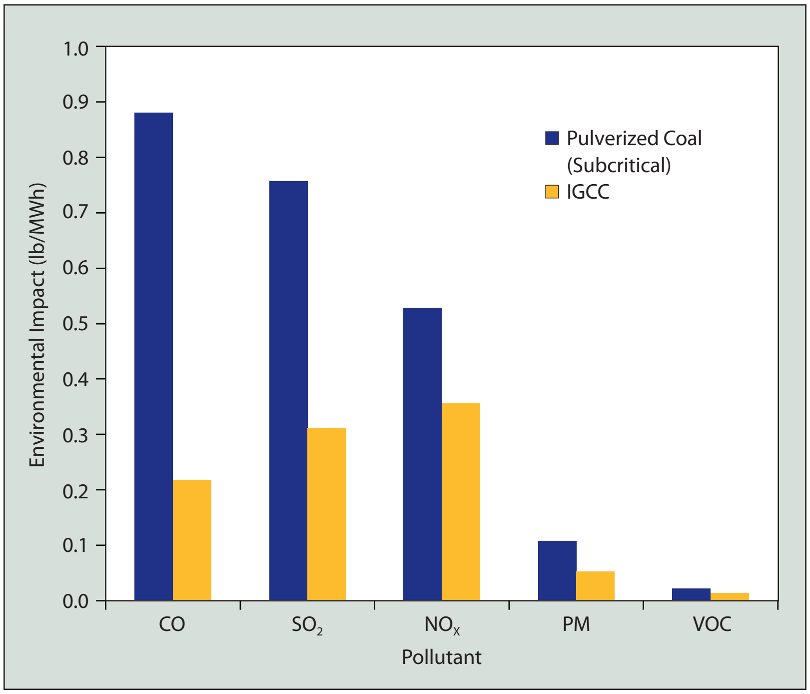
The U.S. government had planned to subsidize a major IGCC demonstration plant with CCS technology called FutureGen. This project, a joint public-private partnership, would have constructed a 275 MW plant in Mattoon, IL, but the DOE withdrew its support in January 2008 due to cost overruns. The DOE has since restructured the FutureGen program to provide funding for the CCS portion of multiple commercial power plants rather than subsidizing an entire plant with CCS; these funds appear to be focused on, but not limited to, IGCC plants.[35] Meanwhile, the private-sector backers of the original FutureGen plant in Illinois have been trying to keep that project alive, and a Senate appropriations subcommittee voted in July 2008 to restore $134 million in funding for that plant.[36]

Most analysts believe that the pre-combustion CCS technology that could be used at IGCC plants is the most advanced and shows the greatest potential for widespread deployment. One prominent study has noted, however, that the race between pre- and post-combustion technologies is not over, and it is too early to declare a winner.[37]

FULL-SCALE, INTEGRATED DEMONSTRATIONS OF CCS AT POWER PLANTS ARE NEEDED

With its potential to play a significant role in helping the world avoid the worst consequences of global warming, CCS technology is gaining attention and research funding around the world. Computer models cited by the IPCC indicate that CCS could eventually contribute between 15 and 54 percent of the CO_2 reductions needed by 2100,[38] and could also lower by 30 percent or more the cost of stabilizing CO_2 concentrations.[39] Most of the analyses reviewed by the IPCC indicate that the majority of CCS deployment would occur in the second half of the century.[40]

FIGURE 10: **Emissions from Pulverized Coal and IGCC Coal Plants**



Compared with new conventional coal-fired power plants, IGCC plants can achieve lower emissions of many common air pollutants including nitrogen oxides, sulfur dioxide, carbon monoxide, particulate matter, and volatile organic compounds. (Figures based on bituminous coal.)

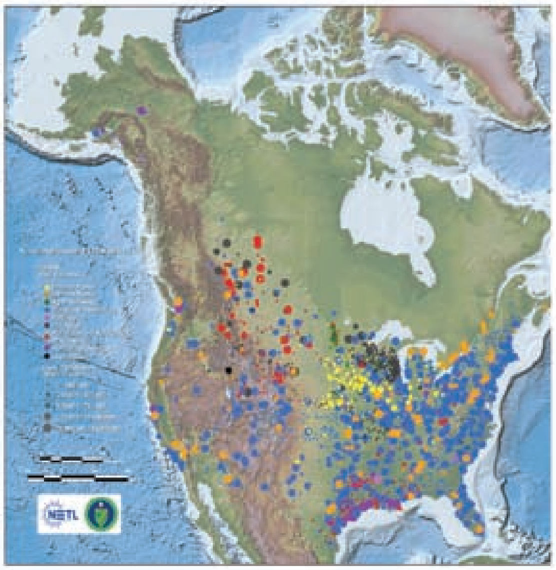
Source: Environmental Protection Agency. 2006. *Environmental footprints and costs of coal-based integrated gasification combined cycle and pulverized coal technologies.*

More recent studies have found that advanced coal plants with CCS technology could make a significant contribution to CO_2 reductions at costs of approximately $25 to $50 per ton of CO_2.[41] (However, as we will discuss in Chapter 3, most of these studies use optimistic cost estimates, which may overstate the likely role of CCS compared with other low-carbon technologies.)

In addition to the IGCC projects noted above that would include pre-combustion CCS technology, several projects have been announced that would test post-combustion CCS at pulverized coal plants. Some of these are relatively small pilot projects that are already under way.[42] Others include larger-scale demonstration projects that would add CCS capability to

FIGURE 11: Potential Geologic Sequestration Sites for CO_2

CO_2 Sources

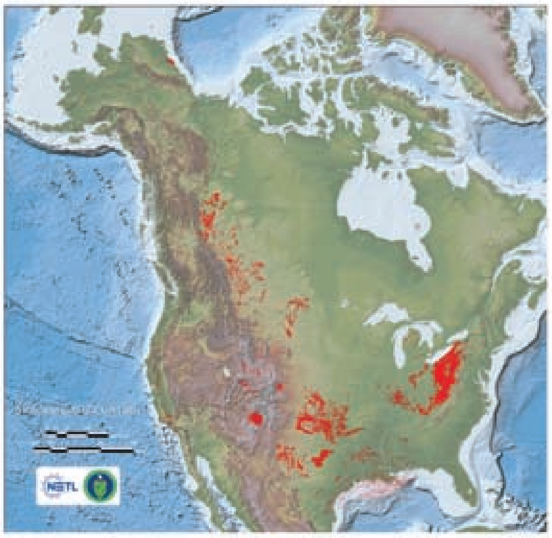


Within the Regional Carbon Sequestration Partnership (RCSP) regions and the northeastern United States, 4,365 facilities generate 3.809 billion metric tons of CO_2.

CO_2 Sequestration Sites: Deep Saline Formations

CO_2 storage capacity in saline formations could be as high as 3,378 billion metric tons for the RCSP regions.

CO_2 Sequestration Sites: Oil and Gas Formations



CO_2 storage capacity in oil and natural gas formations is estimated at 82.4 billion metric tons for the RCSP regions.

CO_2 Sequestration Sites: Coal Seams

Capacity estimates for unmineable coal seams range up to 183.5 billion metric tons for the RCSP regions.

The U.S. Department of Energy estimates that geological formations in North America could store hundreds of years' worth of U.S. CO_2 emissions at the current rate. Appropriate formations could include oil and gas fields, unmineable coal seams, and deep saline aquifers.

Source: National Energy Technology Laboratory. No date. *Carbon sequestration atlas of the United States and Canada*.

existing plants[43] or incorporate CCS into new plants (see Appendix A).[44] These larger-scale projects will generally require policy changes or government incentives to go forward.

In terms of the kinds of geologic formations considered most suitable for carbon sequestration, researchers have identified depleted oil and gas fields, coal seams that cannot be mined, and deep saline aquifers. In North America, these formations together represent a storage potential equivalent to hundreds of years' worth of emissions based on the current U.S. emissions rate of six gigatons per year.[45]

The energy industry already has considerable experience with injecting CO_2 into oil and gas fields, where it is used to increase production in a process called enhanced oil recovery (EOR). This increased productivity can offset some of the costs of the capture and storage process, making power plants near EOR sites the most commercially viable candidates for CCS technology.

However, potential EOR sites are relatively limited in number and not widely dispersed. Such sites may therefore represent only 2 to 7 percent of total North American storage potential.[46] In addition, the U.S. Geological Survey (USGS) has determined that the distances between the largest existing sources of CO_2 (including coal plants) and potential storage sites in large oil and gas fields would require the development of a processing and transportation infrastructure larger than that of the current U.S. natural gas and petroleum industry.[47]

CO_2 can also be sequestered in deep saline aquifers, which could represent a far more abundant and widespread storage option than EOR sites—possibly more than 90 percent of total North American storage potential.[48] However, much less is known about saline disposal than EOR. Researchers are also investigating carbon sequestration in basalt formations, though these are not nearly as widely dispersed as saline aquifers.

Some have also proposed injecting CO_2 into deep ocean waters, but due to significant concern about this strategy's potential environmental impact and potential lack of permanence, interest has declined.[49] More recently, scientists have suggested injecting CO_2 into the sediments on the ocean floor, where the natural temperature and pressure conditions could prevent the CO_2 from rising and mixing with the ocean water.[50] If it is determined that CO_2 can be safely stored in deep-sea sediments (that is, under thousands of feet of seawater and a few hundred meters of sediment), this option would offer vast storage potential[51]—though it would also involve the added cost of transporting the CO_2 out to sea. The strategy has yet to be field tested.

There are multiple small sequestration pilot projects planned or under way around the world,[52] but there are only four major geologic sequestration projects for CO_2 currently in operation. Three—in Algeria, Canada, and the North Sea—have been operating for a few years; the fourth began storing CO_2 off Norway's coast in April 2008. Two of these projects inject CO_2 into saline aquifers (North Sea and Norway), one injects CO_2 into a depleted gas reservoir (Algeria), and one uses the CO_2 for enhanced oil recovery (Canada). None of these projects involve CO_2 captured from coal-fired power plants, however.[53]

Six new projects that will inject CO_2 from various sources into diverse geologic formations have recently been awarded DOE grants. While these are considered large-scale projects, most of them are smaller in scale than the four existing projects described above.[54] Two plan to obtain CO_2 from post-combustion capture added to existing coal plants.

The four existing sequestration projects described above each sequester between 0.75 million and 1.5 million tons of CO_2 annually, and the largest of the six new DOE-funded field tests will sequester about 1 million tons annually.[55] Unfortunately, a single new 600-megawatt (MW) coal plant emits more than 4 million tons per year—equivalent to the volume of approximately four Empire State Buildings.[56] For CCS to play a major role in reducing global warming pollution, we would need thousands of sequestration projects the size of those described above.

THE RISKS POSED BY COMMERCIAL CCS ADOPTION MUST BE ADDRESSED

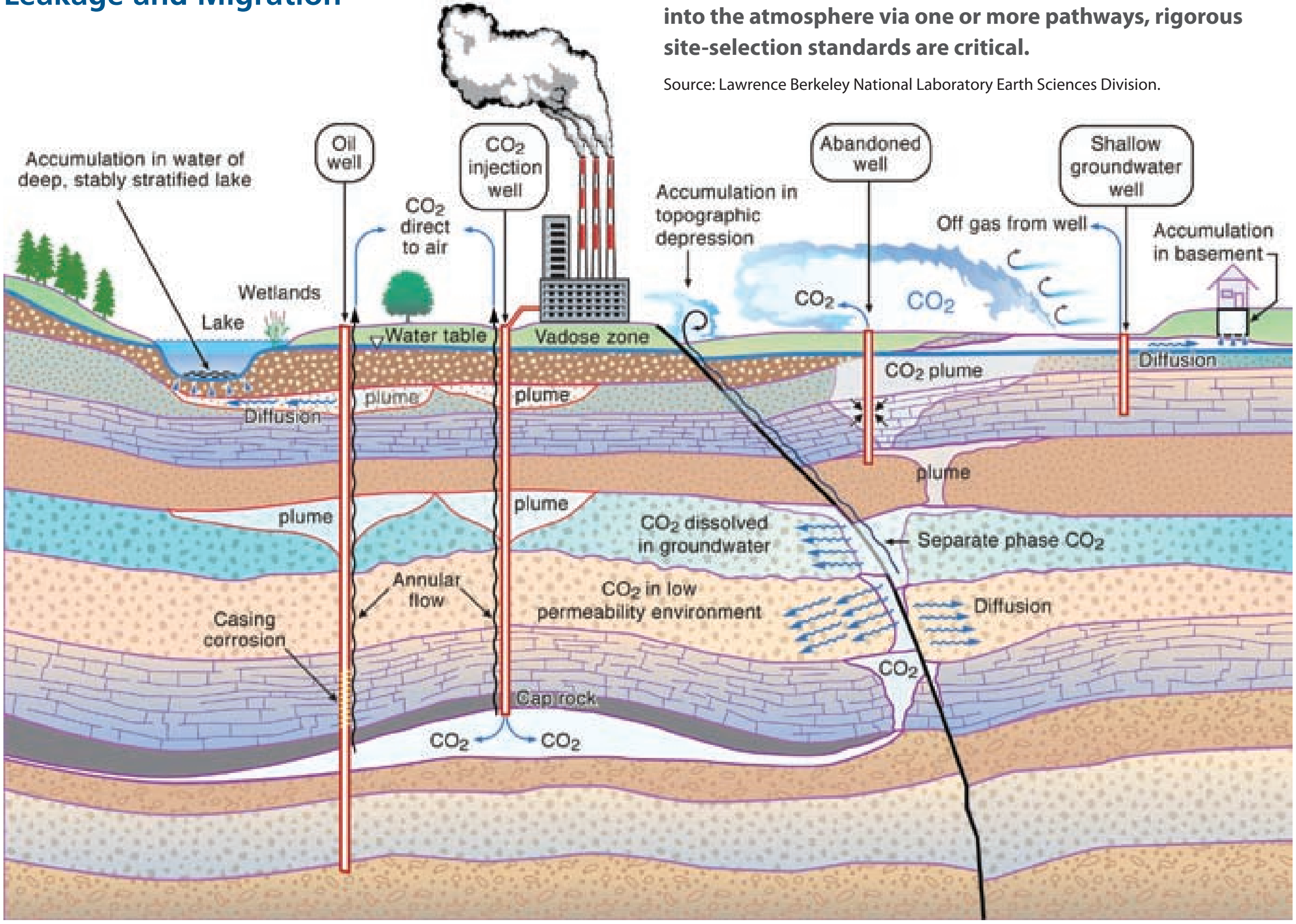
CCS technology comes with its own set of environmental and health risks, including the risk of slow leaks that would undermine its capacity for reducing global warming pollution.[57] Rapid leaks of CO_2, either from a storage site or pipeline, could pose a local danger since high concentrations of this gas can be fatal.[58]

CO_2 could also migrate underground and contaminate freshwater aquifers.[59] This risk would increase in the presence of abandoned oil and gas wells that can provide conduits for migration. It is even possible that injecting massive quantities of CO_2 into the ground could trigger earthquakes, though the risk is considered small.[60]

FIGURE 12: Possible Routes of CO_2 Leakage and Migration

Because geologic sequestration carries the risk that injected CO_2 could migrate into freshwater aquifers or be released into the atmosphere via one or more pathways, rigorous site-selection standards are critical.

Source: Lawrence Berkeley National Laboratory Earth Sciences Division.



The permanence of CO_2 storage is the greatest concern from a global warming perspective. Because this gas has the potential to contribute to global warming for hundreds and possibly thousands of years, it is essential that long-term leakage rates be very small.

Detailed analyses of CCS have concluded that long-term storage is technically feasible, and that the risks are not unlike those faced in other industrial activities.[61] The authors of one prominent report concluded that they have "confidence that large-scale CO_2 injection projects can be operated safely."[62] The IPCC concluded that CO_2 could generally be contained for millions of years, with over 99 percent of the injected CO_2 likely to be retained for more than 1,000 years provided the storage sites are well-selected, -designed, and -managed.[63]

Therefore, the key to minimizing the risks of CCS will be implementing a regulatory system that imposes strict standards on site selection, project design, operation, and long-term monitoring. Unfortunately, there can be tension between the need to regulate new technologies and the need to keep the deployment costs of new technologies down, particularly with technologies that may be only marginally competitive economically.

Experience with enforcement of coal mining and nuclear power regulations in the United States creates uncertainty about how current and future regulators would balance the costs and risks of CCS, particularly if the economic stakes for the industry are high.[64] This uncertainty is increased by the fact that difficult-to-quantify risks are imposed far into the future, when the economic viability of companies responsible for managing the risks cannot be known.

These risks are compounded by unanswered liability questions. Because the risks associated with long-term CCS are difficult to quantify, analysts expect private insurance to be costly or possibly even unavailable. Some have therefore proposed legislation limiting the liability of companies engaged in CCS or exempting them from liability altogether, similar to the limits granted to the nuclear power industry under the Price-Anderson

Act and subsequent extensions. As we have seen with the nuclear industry, however, limiting liability has adverse consequences: it reduces the incentive for companies to manage their operations safely, and effectively provides a subsidy that gives liability-limited technologies a competitive advantage over technologies that must be fully insured against liability.

The risks of CCS must also be considered in light of the sheer scale of the industry. For example, even if CCS were responsible for just one-tenth of the needed CO_2 reductions, the volume of liquefied CO_2 being actively managed could approximately equal the amount of oil currently flowing around the world.[65] And if CCS becomes a global strategy for reducing CO_2 emissions, the quality of regulation in other countries also becomes important. Regulation of China's coal mining and emissions, for instance, is considered far weaker than U.S. regulation.

The current status of CCS technologies and projects is reviewed in Appendix A, along with a more detailed discussion of the risks. It should be noted that other technologies and strategies for reducing global warming pollution also involve risks and uncertainties, including the risk that these technologies may not be enough to avoid the worst consequences of global warming. CCS technology holds sufficient promise that commercial-scale demonstration projects can and should be undertaken (see Chapter 3). These projects can inform subsequent decisions about whether mass deployment of CCS is warranted and cost-effective.

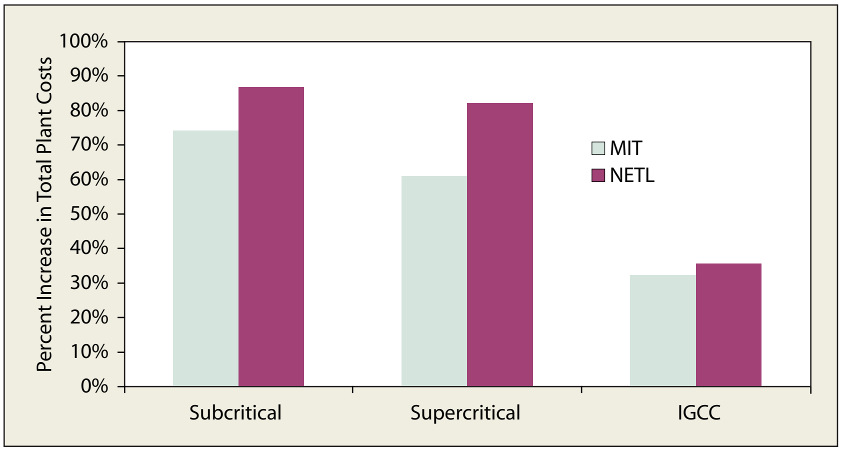
Cost is another key challenge for the CCS technologies currently under consideration, all of which would substantially increase the cost of energy production (even if the technology is part of the plant's original design). According to one estimate, adding carbon capture to a pulverized coal plant would increase its cost of energy between 60 and 78 percent. Adding carbon capture to an IGCC plant would increase its cost of energy between 29 and 36 percent.[66] The increased cost of energy reflects, among other things, the substantially higher projected cost of building coal plants with CCS, especially pulverized coal plants (see Figure 13).

While building an IGCC plant without carbon capture costs somewhat more than building a pulverized coal plant without capture, studies show that the cost advantage switches to IGCC plants when carbon capture is added.[67] In either case, there would be additional costs associated with transportation of the CO_2 to a sequestration site, injection of the CO_2, and long-term monitoring of the site.

The DOE has established a 2012 goal of reducing the incremental cost of adding CCS technology to 10 percent for an IGCC plant and 20 percent for a pulverized coal plant.[68] These reductions seem unrealistically ambitious given the short time frame allotted for demonstrating the technology at commercial scale, the long lead time needed to build IGCC plants (five to six years), and the recent escalation in capital costs for power plants and other large construction projects.

Another reason why the cost of energy rises dramatically when carbon capture is added is that the process of separating and compressing the CO_2 (which is necessary for transportation and sequestration) is highly energy-intensive. Amine scrubbing, for example—the current state-of-the-art capture method for pulverized coal plants—is expected to reduce the plant's energy output by a quarter or more (assuming CCS is built into the original plant design and not

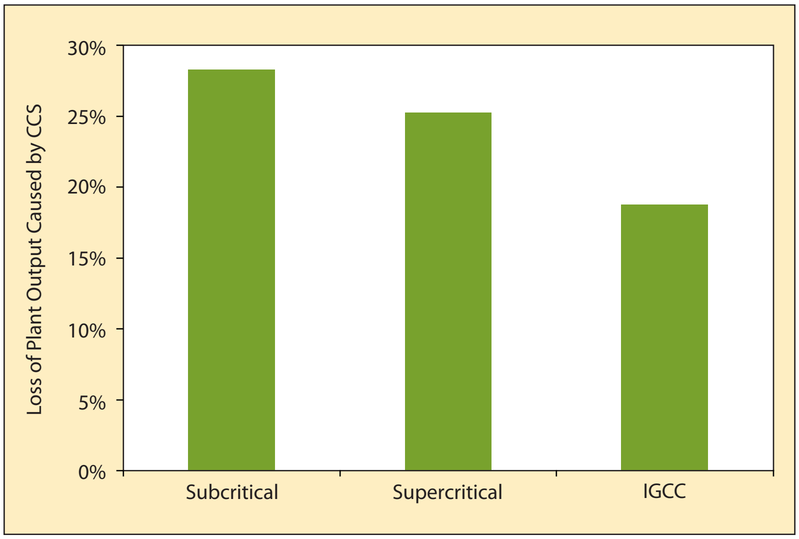
FIGURE 13: Costs of Adding Carbon Capture to Coal-fired Power Plants



While IGCC plants without CCS are expected to cost more than conventional (i.e., pulverized coal) plants without CCS, adding CCS to an IGCC plant is expected to cost considerably less than adding it to a conventional plant.

Sources: Massachusetts Institute of Technology, 2007. *The future of coal: Options for a carbon-constrained world.* And: National Energy Technology Laboratory. 2007. *Cost and performance baseline for fossil energy power plants study, Volume 1: Bituminous coal and natural gas to electricity*.

FIGURE 14: Loss of Plant Output Caused by Carbon Capture



Adding carbon capture to a coal plant is expected to substantially reduce its efficiency and therefore its electrical output. The loss of output is expected to be less for IGCC plants than for pulverized coal plants.

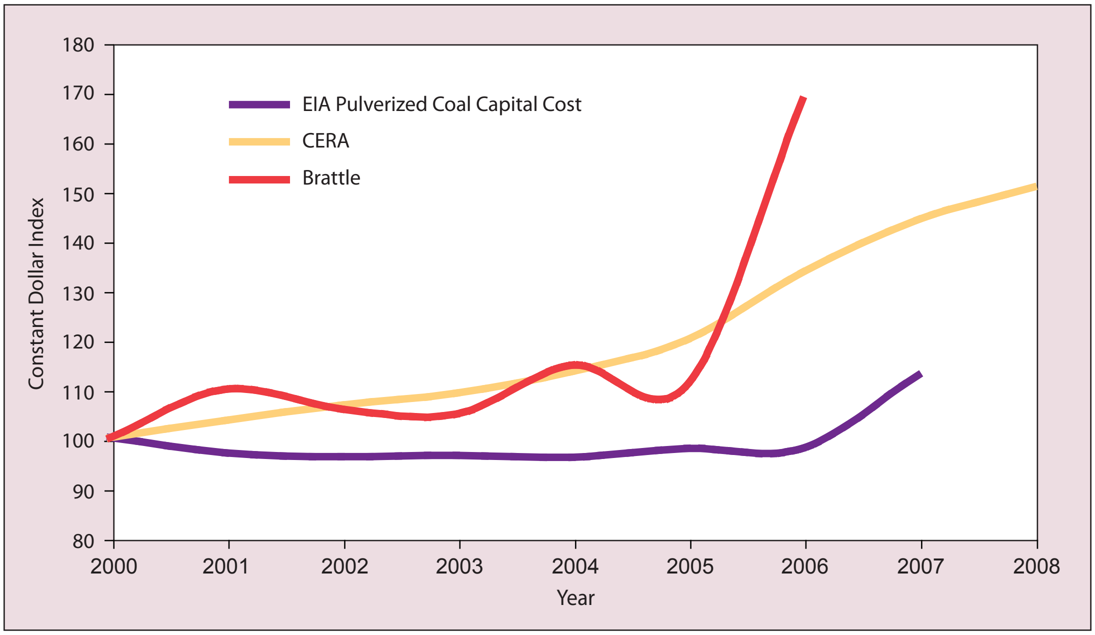
Source: Massachusetts Institute of Technology. 2007. *The future of coal: Options for a carbon-constrained world.*

added as a retrofit).[69] The output of IGCC plants will also be reduced by adding carbon capture, but not by as much (see Figure 14).[70]

These efficiency losses mean that coal plants with CCS would require more coal to generate the same amount of power as a plant without CCS, increasing the environmental and societal damage caused by coal mining and processing (see Chapter 8 and Appendix B). Stated in other terms, it is like having to build one new coal plant just to power the carbon capture process for every three to four conventional plants or every four to eight IGCC plants. This, in turn, increases the risk of adopting CCS should long-term storage not prove as effective as anticipated.

It should be noted that most studies have probably underestimated the cost of adding CCS to coal plants because they do not reflect the recent escalation in construction, material, and labor costs. For example, as discussed in Chapter 3, the estimated cost of the 275 MW FutureGen project increased from $950 million to $1.8 billion (or $6,545 per kilowatt) before the federal government withdrew its support. Even though this first-of-its-kind project was relatively small, its capital costs still proved to be two to three times higher than what most studies had anticipated. Several utilities have cited the increase in capital costs as one of the main reasons behind their recent decisions to cancel or delay coal plant projects (without CCS). Construction cost escalation has affected all types of generation, however, and fuel costs have also increased, complicating long-run projections of the competitiveness of generation options.

FIGURE 15: Power Plant Construction Cost Escalation, 2000–2008



Power plant construction costs have increased by 50 to 70 percent since 2000 (in constant inflation-adjusted dollars), according to two recent reports. Many recent studies have not included this cost escalation when making projections for building new power plants under different scenarios. For example, the U.S. Energy Information Administration assumed no increase in coal-fired power plant capital costs until 2007, when it applied a 15 percent cost increase to all technologies.

Sources: Energy Information Administration. *Annual energy outlook* 2000 through 2008. And: Cambridge Energy Research Associates. 2008. Power capital costs index. And: Chupka, M.W., and G. Basheda. 2007. *Rising utility construction costs: Sources and impacts.* The Brattle Group. September. All indices are modified by UCS to be in constant dollars using a GDP deflator.

CHAPTER THREE

The United States Should Accelerate CCS Demonstrations

Given the urgent need to address global warming and the potential role CCS technology can play in achieving deeper emissions cuts, the U.S. government should provide direct support to accelerate CCS demonstration projects. At the same time, given the uncertainty surrounding the technology's suitability for widespread deployment and the environmental and safety costs associated with coal use, the United States must also take steps to:

- reduce those environmental and safety costs (see Chapter 7 and Appendix B);
- accelerate investments in less risky low-carbon technologies such as energy efficiency and renewable energy (see Chapter 6); and
- avoid policies that would bias investment decisions in favor of CCS rather than less risky low-carbon technologies.

One proposed mechanism for promoting CCS projects is the adoption of a "low-carbon generation obligation" (LCGO), which would require all generators of coal power to obtain a small but growing percentage of their power from coal plants with CCS.[71] Generators would also have the option of purchasing marketable credits from such plants instead of the actual power. In this way, the first CCS projects would be subsidized by the nation's producers of coal power, in proportion to their dependence on coal. Such a proposal was included in S.309 (Sanders-Boxer; Global Warming Pollution Reduction Act of 2007).

However, this policy would require the building of a large number of coal plants with CCS in the years ahead, even if the early results from the first demonstration projects show that CCS is not safe or is far costlier than the alternatives. Indeed, S.309 could require more than 16,000 MW of new capacity supplied by coal plants with CCS—the equivalent of about 27 new 600 MW plants—by 2020.[72] Making such a major commitment to a technology that has yet to prove itself at commercial scale appears unwarranted at this time, particularly when we have yet to fully pursue more cost-effective energy efficiency and renewable alternatives.

Others have proposed various subsidies for CCS that would apply to a larger number of projects, or for longer periods. These proposals include mechanisms such as federal production tax credits,[73] special carbon-allowance allocations,[74] and state regulatory subsidies, such as allowing companies to charge customers for construction work in progress. And as mentioned previously, some have proposed exempting CCS projects from liability.[75]

Unfortunately, such proposals would tilt investment decisions toward continued dependence on coal—the fuel with the most damaging impacts over its life cycle—rather than to inherently cleaner low-carbon or zero-carbon options. Energy efficiency and renewable energy technologies, for instance, may not only have significantly lower impacts and risks than coal with CCS, but also lower costs. Any direct incentives for CCS must therefore be limited to research and development (R&D) plus the specific number of projects needed to make the technology ready for deployment on a large scale (if such deployment proves warranted).

As the technology becomes proven at commercial scale, it should be eligible to compete against other carbon-reducing technologies for additional support, by way of an evaluation process that considers both direct and indirect costs and risks over the full life cycle. We recommend that no energy technologies be exempted from liability; instead, energy producers should be required to obtain private insurance (thereby internalizing risks in their direct costs) and should be offered appropriate incentives to minimize such risks.

FIVE TO 10 DEMONSTRATION PROJECTS ARE NEEDED

Rather than provide blanket subsidies to deploy a technology that has not yet been proven at commercial scale, the federal government should provide support targeted to the specific number of CCS projects needed to determine the technology's technical and economic feasibility. Such an approach would open the door to more widespread deployment of CCS but allow us to wait until the results are in before we decide whether to walk through that door.

Our review of the issue and the literature suggests that funding between 5 and 10 CCS demonstration projects, using various technologies and reflecting different types of geologic sequestration sites, would provide enough data to make an informed decision within a few years about the appropriate level of investment in this technology. All demonstration projects must of course involve very careful selection and long-term monitoring of sequestration sites, which in turn requires the development of site selection and monitoring protocols. Such protocols will not only improve the safety and usefulness of the demonstration projects, but also enable us to more rapidly deploy CCS technology later if we decide to do so. The lack of such protocols has often been identified as a major barrier to the eventual widespread deployment of CCS.[76]

A recent Massachusetts Institute of Technology (MIT) study strongly favors additional support for CCS technology. Though the authors state that large-scale and integrated demonstration of CCS should be a national priority, they find current support for such demonstrations to be woefully inadequate, and recommend it be expanded to include "up to five [CCS] projects of different types (power, fuels, chemicals, synthetic gas; new plants, retrofits)."[77] The authors do not explicitly state how many demonstration projects should focus on the power sector, though the above language suggests that three of the five would apply to either new or existing plants making fuels, chemicals, and synthetic gas, leaving only two in the power sector. We can therefore infer that the authors believe a very limited number of CCS power plant projects would yield the information needed to support a wide deployment of this technology later.

The question of how many demonstration plants should be built was examined in more detail in a recent report published by the Pew Center on Global Climate Change.[78] The smaller-scale program proposed by the author would provide funding for 10 commercial-scale CCS demonstration projects at coal-fired power plants and five at industrial sites; the larger-scale program would fund 30 demonstrations at power plants and 10 at industrial sites. The author asserts that the smaller-scale program would "establish reliable CCS cost and performance data" and build experience with CCS, while the larger-scale program would also "achieve significant reductions in CO_2 capture costs and energy penalties, build broad public acceptance of CO_2 storage, and promote the timely development of CCS regulatory systems."[79]

The larger-scale program does not, however, assume that the proposed demonstration projects are built at the same time. Rather, its projected reductions in costs and energy penalties are based on "successive age-classes or generations of plants, each incorporating lessons from earlier plants."[80] Specifically, the author assumes a first age-class of only four plants (with about 400 MW of net capacity each), followed by three additional and larger age-classes,[81] the last of which would be built in 2020.[82]

Executing this plan would require an extremely ambitious design and construction schedule of about three years per age-class (i.e., starting today, each class would need to become operational in 2011, 2014, 2017, and 2020). In other words, the designers of each succeeding age-class would have an average of only three years to glean design lessons from the previous class, incorporate those lessons into the new designs, and obtain funding and approval for their projects. Yet even some coal plants without CCS that are already well along in their development phase are not projected to commence operation until 2013 or later, suggesting that coal plants with CCS will require far more than three years per age-class. The process could presumably be accelerated if, as discussed below, demonstration projects focused on the retrofitting of existing plants rather than the construction of new ones.

We recommend sufficiently funding the first age-class of CCS demonstration projects and assessing its effectiveness before committing to subsequent age-classes. The question is how many demonstration projects should be in that first age-class, and that decision should be based on how many projects are needed to test the different CCS technologies that could merit investment. IGCC technology with pre-combustion carbon capture should certainly be tested because it appears the most promising.

Post-combustion capture from pulverized coal plants should also be tested, since we must dramatically reduce emissions from existing plants if we are to avoid the worst consequences of global warming. Such demonstrations will help us determine whether it is more cost-effective to retrofit our old plants with post-combustion capture, replace them with IGCC plants using pre-combustion capture, or replace them with other low-carbon technologies.

There are at least three different kinds of post-combustion capture technology worth demonstrating:

amine scrubbing, chilled ammonia, and "oxy-firing" (see Appendix A). Where the results can be expected to differ significantly based on whether the project uses bituminous or sub-bituminous coal, it may be worth funding demonstrations using each type.

We also recommend testing options for combining biomass with coal, as well as exclusively biomass-fired IGCC power plants with CCS, because as we note above such plants could actually achieve negative carbon emissions. More unconventional types of carbon capture that are currently in the experimental phase, such as the use of algae, should also be actively investigated.[83] Finally, we recommend that whatever capture technologies are ultimately demonstrated, these projects should address sequestration in a range of different geologic formations (oil fields, saline formations, basalt formations).

Given the number of technologies worth demonstrating, we believe the MIT report's recommendation to fund less than five CCS demonstrations in the power sector may be insufficient. On the other hand, the Pew report's larger-scale program (funding 30 power plant projects and 10 others) is unnecessarily large. Our recommendation, funding 5 to 10 demonstration projects (with the high end comparable to the Pew report's smaller-scale program),[84] is both needed and sufficient to test the range of CCS technologies currently under development and to address a range of sequestration sites.

Ideally, these U.S. projects would be carefully integrated with the ongoing international effort to investigate and demonstrate CCS technology. The International Energy Agency (IEA) has released a CCS development road map that contemplates the involvement of numerous countries in Asia, Europe, and North America and sets a target of 20 to 30 CCS demonstrations at power plants (including coal, gas and biomass plants) by 2020.[85] The European Union has established the EU Flagship Programme, with the goal of constructing up to 12 CCS demonstration plants by 2015.[86] And various CCS projects related to power plants are already under way or under consideration in Australia, Canada, China, and Europe.[87] U.S. demonstration projects should avoid redundancy with these international efforts and ensure that the most promising CCS options are investigated.

FIGURE 16: Scale of CCS Proposals

Source	Number of Projects Proposed	Types of Projects
United States		
MIT [1]	5	coal plants, fuels, chemicals, and synthetic gas with CCS
UCS	5–10	coal plants with CCS
Pew smaller-scale [2]	10	coal plants with CCS
Pew larger-scale [2]	30	coal plants with CCS
Multinational		
EU [3]	up to 12	coal and other fossil-fueled power plants with CCS
IEA [4]	20–30	coal, gas, and biomass-fueled power plants with CCS

1 Massachusetts Institute of Technology. 2007. *The future of coal: Options for a carbon-constrained world.*

2 Kuuskraa, V.A. 2007. *A program to accelerate the deployment of CO_2 capture and storage (CCS): Rationale, objectives, and costs.* Coal initiative reports. Arlington, VA: Pew Center on Global Climate Change.

3 European Technology Platform for Zero Emissions Fossil Fuel Power Plants (ETP ZEP). 2008. The EU Flagship Programme for CO_2 capture and storage (CCS), ZEP recommendations: Implementation and funding.

4 International Energy Agency. 2008. Energy technology perspectives 2008: Scenarios and strategies for 2050.

CCS demonstration projects of varying sizes have been proposed by MIT, the Pew Center on Global Climate Change, the European Union, and the International Energy Agency. Numbers for the MIT, EU, and IEA demonstration projects include technologies other than coal-fired power plants.

DEMONSTRATIONS SHOULD ACHIEVE ACTUAL EMISSIONS REDUCTIONS

U.S. demonstration projects should focus on reducing global warming pollution from our existing fleet of aging and highly polluting coal plants. As discussed above, building new coal plants without CCS and then retrofitting them with the technology is not cost-effective, but studies have indicated that it may be cost-effective to rebuild (or "repower") inefficient plants built decades ago.[88] Such repowering projects would remove two of the central components of a pulverized coal plant—the boiler (where the coal is burned and steam created) and the generator (where the steam produces electricity)—and replace them with much more efficient models. Carbon capture technology could be cost-effectively integrated into a plant at the same time.

Repowering would allow demonstration projects to take advantage of existing plant infrastructure such as coal delivery facilities, water access facilities, chimneys, and power lines—structures that are expensive to build from scratch. This approach would also accelerate demonstration projects by eliminating the site decisions and construction associated with building a new plant.

If a promising technology cannot be demonstrated except as part of a new plant, that plant should be one that demonstrably replaces power from an existing coal plant. This would ensure that such demonstrations contribute to the overriding goal of reducing emissions on the ambitious scale and timeline that the science shows us is needed.

Furthermore, CCS demonstration projects should fully integrate carbon capture, transportation, and storage. These elements have been shown to work at a generally small scale in industrial applications; what is needed now is to integrate them at commercial scale with an operating coal-fired power plant at one end of the process and a safe, well-monitored sequestration site at the other.

The Pew report defines commercial-scale as 400 MW (after the energy lost to carbon capture technology has been subtracted).[89] A coal plant this size may be smaller than the typical new plant (many of which are 600 MW or larger), but should be large enough to assess the technology's commercial viability, and in some cases may be larger than necessary. Commercial-sized projects might be usefully preceded by pilot-scale projects for CCS technologies that have yet to be demonstrated at such a scale.

The question of who will hold the intellectual property (IP) rights to the technologies emerging from these demonstration projects will need to be given careful consideration, since each project will involve both public and private investment. IP issues become even more complex when there is the prospect of different nations jointly pursuing such projects and where there is a need for developed nations including the United States to transfer technologies to developing nations (see Chapter 10). On the one hand, it is important to reward companies for the risk they have taken investing in innovative technologies, especially at a time when we seek to accelerate the development of such technologies. On the other hand, it is also important to recognize the public's interest in (and substantial funding of) innovative technologies, and to ensure that restrictive IP rights do not hinder their widespread deployment.

DEMONSTRATIONS CAN BE FUNDED BY CAP-AND-TRADE REVENUES

Funding for CCS demonstration projects should eventually come from a small portion of the revenue accrued by auctioning pollution allowances under a federal cap-and-trade program (see Chapter 9). If the demonstrations are successful in showing that CCS can be a viable commercial-scale climate solution, future advanced coal and CCS projects should be eligible to compete for a limited amount of auction revenues until the technology is fully commercialized. However, since it may be some years until a federal law is passed and auctioning actually begins, CCS demonstration projects should be funded for the time being by a small fee paid by operators of existing coal plants or by diverting existing subsidies.

The costs associated with 5 to 10 demonstration projects of the sort we have discussed are difficult to project because there are no existing coal plants with CCS to serve as a model, and the costs will vary based on the number of projects and the technologies selected. The Pew report forecasts costs that are likely close to the investment we recommend: its smaller-scale program (10 coal plant projects along with five industrial projects) would cost between \$8 billion and \$10.2 billion. These estimates assume that adding CCS to a 390 MW pulverized coal plant would cost between \$480 million and \$650 million, while adding the technology to an IGCC plant with similar output would cost between \$310 million and \$570 million.[90] In both cases a substantial share of this cost relates to the power lost when CCS is added; the additional costs are associated with CO_2 transportation and storage, and with the five industrial plants.

The Pew report concludes that this program could be funded over 10 years with a fee of \$0.40 to \$0.50 per megawatt-hour (MWh) paid by the nation's coal-fired power plants (plus a fee of \$0.50 per metric ton on CO_2 emissions from industrial sources).[91] This represents a virtually imperceptible increase in the cost of coal power—by way of comparison, power from an older, fully depreciated coal plant costs approximately \$20 to \$30 per MWh, while power from a newer plant can cost \$65 to \$80 per MWh (not including a potential fee for CO_2 emissions).

This source of funding should also be used to support detailed geologic surveys of possible U.S. sequestration sites. The MIT report finds current efforts inadequate, and recommends that the DOE and USGS undertake a formation-specific review of possible sites in relation to major coal-burning facilities.[92] The authors also recommend other nations do the same, which they conclude can be done for about "\$10–50 million for a given continent."[93] The results of such a survey will be necessary to enable the wider deployment of CCS later (if the demonstration projects show it to be warranted), so its relatively modest cost should be added to the demonstration program budget.

The Pew report recommends that the demonstration program subsidize only the incremental costs associated with CCS (including capital costs and costs associated with lost production for a limited number of years), not the costs associated with the underlying generating technology. We generally agree with this approach, but strict application of such a policy could inappropriately disadvantage IGCC technology. Without carbon capture, an IGCC plant costs more than a pulverized coal plant, but the cost advantage likely switches to IGCC when CCS is included. The demonstration program should therefore consider funding the incremental cost of building an IGCC plant with CCS compared with building a conventional coal plant without CCS.

Before the DOE withdrew its support in February 2008, the 275 MW FutureGen project was expected to cost $1.8 billion ($6,545 per kilowatt), far more than its original estimate of $950 million (and two to three times more than what many experts have estimated CCS technology will ultimately cost).[94] The MIT report criticized FutureGen for a lack of clarity about project objectives and the inclusion of features unnecessary for a commercial demonstration plant.[95] Whatever the cause of this project's cost overruns, it should be expected that commercial demonstration of CCS will be costly, and that initial cost estimates must be taken with a grain of salt. However, a demonstration project that adds CCS to an existing plant should cost significantly less than the FutureGen plant. The DOE's "restructured" approach to CCS demonstration moves in this direction by offering to fund just the CCS component of power plants rather than the whole plant.[96]

To put the potential cost of CCS R&D into perspective, consider that the 114 coal plants without CCS currently being proposed represent a capital investment of at least $144 billion (assuming a construction cost of $2,200 per kilowatt for a pulverized coal plant). From a purely fiscal standpoint, investing that amount of money into technology we know is incompatible with a carbon-constrained world is financially far riskier than investing $10 billion or so into CCS demonstration projects that could yield a technology capable of fighting global warming. Avoiding the worst consequences of global warming clearly warrants investments of this scale, and not just in CCS technology but also—indeed, especially—in energy efficiency, renewable energy, and energy storage technologies. In Chapter 7 we discuss the need to complement CCS demonstration projects with greatly enhanced funding for R&D and demonstrations of these inherently cleaner technologies too.

DEMONSTRATIONS COULD YIELD INITIAL RESULTS BY 2013–2015

As discussed above and in Appendix A, many CCS projects are already in development around the world, including some large-scale efforts. Few have actually commenced construction, and in some cases the project backers have explicitly stated that they are waiting for changes in public policy to make such projects worthwhile. Still, this suggests that demonstration projects could begin relatively quickly once the financial incentive exists. Assuming projects could commence in 2010, those that do not involve the construction of an entirely new plant could be operational by 2013, while those that do could be operational by 2015.

By the middle of the next decade, therefore, we should have useful information that will help us decide whether CCS is as promising as its backers claim or whether we should invest in other, more promising technologies. In the meantime, progress in all of these technologies should continue to improve their pricing and performance.

RECOMMENDATIONS ON CCS DEMONSTRATIONS

- The United States should support 5 to 10 CCS demonstration projects covering the most promising carbon capture technologies and geologic formations. Each project should produce actual reductions in CO_2 emissions by retrofitting existing coal plants or by displacing power from such plants. As the technology becomes proven at commercial scale, it should be eligible to compete against other carbon-reducing technologies for additional government support.
- Demonstration projects should be initially funded by a small fee paid by operators of existing coal plants, and eventually funded by a small portion of the proceeds from cap-and-trade auctions.
- Any demonstration program must include the development of regulatory protocols for selecting and monitoring sequestration sites.
- The United States should simultaneously launch a detailed survey of potentially suitable geologic formations.

CHAPTER FOUR

The United States Should Stop Building Coal Plants without CCS

While we need additional information to decide how much to invest in coal plants that capture CO_2, it is already clear that further investments in new coal plants that do *not* capture CO_2 would be a mistake. Federal policy should therefore prevent the construction of any new coal plant unless it employs CCS.

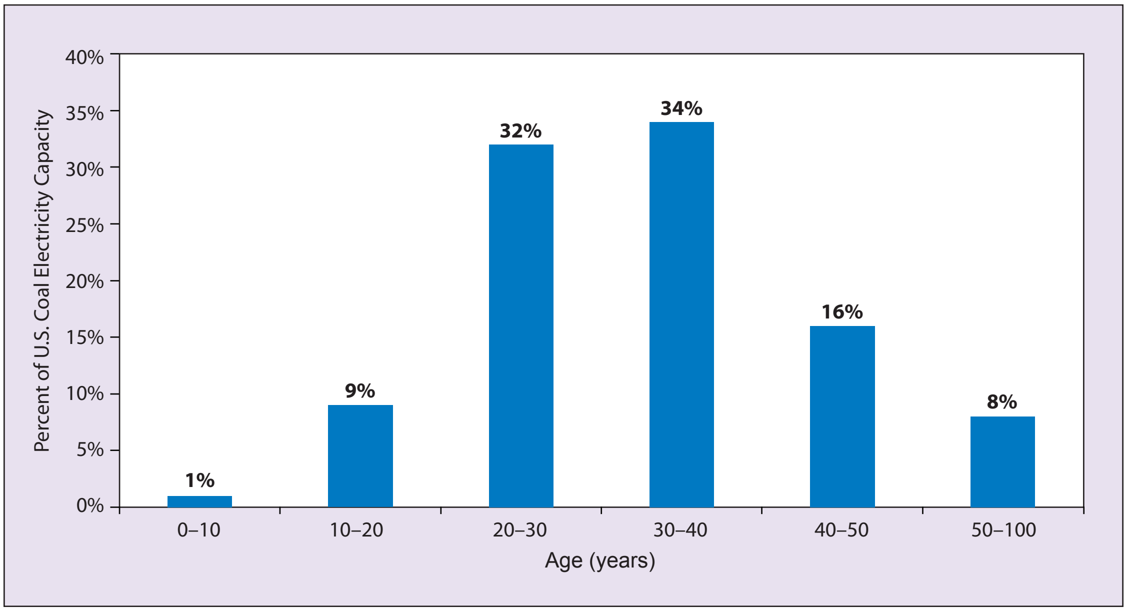
NEW COAL PLANTS WILL STILL PRODUCE ENORMOUS AMOUNTS OF CO_2

As discussed earlier, virtually all the new coal plants that have been proposed will, just like their predecessors, release 100 percent of the CO_2 they produce into the atmosphere, where it will linger—and contribute to global warming—throughout this century and into the next. Advocates of new coal plants frequently argue that new plants emit less CO_2 than old ones and may be seen as a "step in the right direction." However, this argument assumes that we can take far more time to make the needed emissions reductions than we can actually afford.

No one can argue the fact that the existing U.S. coal fleet is old and inefficient; the average age of each plant is over 35 years, and the average efficiency is roughly 33 percent.[97] In other words, for every three tons of coal a plant burns, one ton is converted into electricity while two tons are lost as waste heat. The third of the coal fleet built before 1970 has even lower efficiency—averaging only 28 percent—and higher emissions.[98]

In terms of efficiency, new IGCC plants are expected to average about 38 percent.[99] The efficiency of new pulverized coal plants varies depending on type (see the text box): less advanced subcritical units have efficiencies of only 33 to 37 percent, more advanced supercritical units have efficiencies of 37 to 40 percent, and the most advanced ultrasupercritical units (operating in Europe and Japan) have operating efficiencies above 40 percent.[100]

FIGURE 17: Distribution of U.S. Coal-fired Power Plants by Age



The U.S. fleet of coal-fired power plants is old—90 percent of the plants are more than 20 years old, and over half of the plants are more than 30 years old.

Source: Wilder, C.J. 2006. Presentation at EEI Conference, November 7. Online at *http://library.corporate-ir.net/library/10/102/102498/items/220201/txu_110906.pdf.*

Remarkably, only 17 of the proposed pulverized coal plants would use supercritical technology, while 40 would use the least-efficient subcritical technology.[101] Twenty-four proposed plants would use subcritical circulating fluidized bed (CFB) technology; these plants potentially represent a greater climate threat than pulverized coal plants because they produce much higher levels of heat-trapping nitrous oxide.[102]

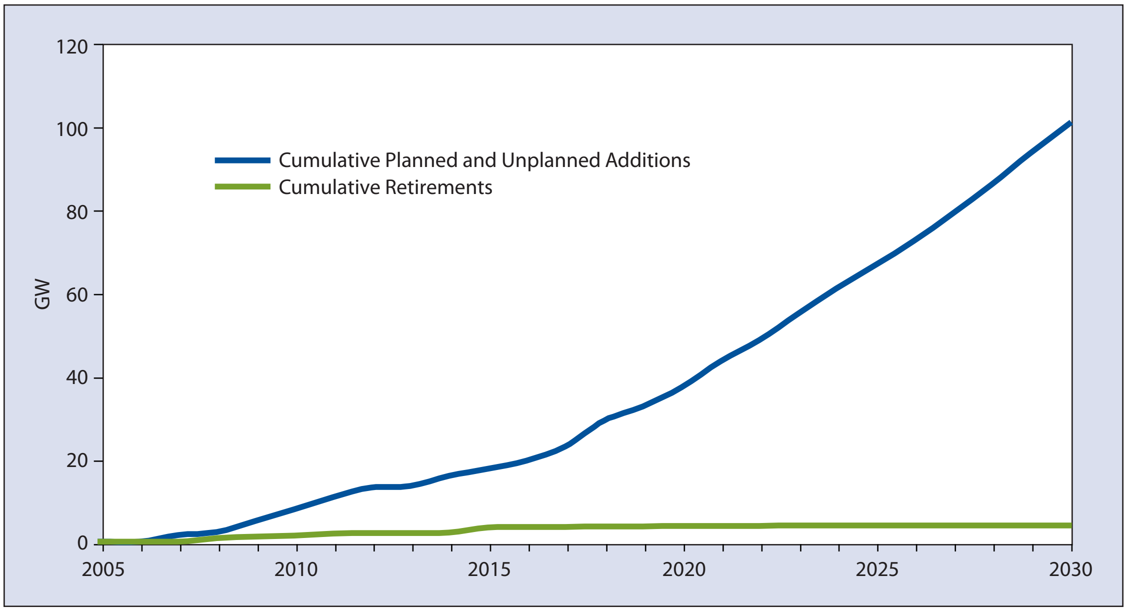
Even if the proposed plants were all substantially more efficient than today's plants, that would not reduce CO_2 emissions by a single ton unless the newer plants actually replace older ones—which is not intended for most of the proposed plants. In the states that require power producers to show that a new coal plant is needed before it can be built (many states do not), producers generally claim the new plants are needed to meet growing electricity demand. In the absence of policy changes, this would be consistent with the Energy Information Administration's (EIA's) 2008 projection of a dramatically expanded U.S. coal fleet by 2030: 100 gigawatts (GW) of new coal plant construction and the retirement of only 3.9 GW of older plants.[103]

One reason why the newly proposed plants are so costly is that they often require the construction of new power lines, coal delivery or handling facilities, and cooling water systems—all costs that could be avoided if these projects were actually designed as replacement plants rather than additions to the fleet. In short, these new coal plants would each emit

Pulverized Coal Plant Technologies

- Most coal-fired power plants in the United States are classified as "**subcritical**" because they operate at steam pressure levels and temperatures below certain thresholds (about 3,200 psi and 1,025°F, respectively). These are the least advanced coal plants, with an average efficiency between 33 and 37 percent.
- More advanced pulverized coal plants are considered "**supercritical**" because they operate at higher pressures and temperatures (about 3,530 psi and 1,050°F, respectively). These plants have an average efficiency between 37 and 40 percent.
- In Europe and Japan, a number of pulverized coal plants known as "**ultrasupercritical**" are capable of even higher pressures and temperatures (about 4,640 psi and 1,112 to 1,130°F, respectively), resulting in an average efficiency above 40 percent.
- A variation on pulverized combustion is **circulating fluidized bed** (**CFB**) technology, which can burn low-quality coal or waste fuels and can co-fire biomass.

FIGURE 18: Construction and Retirement of U.S. Coal-fired Power Plants



The U.S. Energy Information Administration projects that, unless policies change, the nation will build 100 gigawatts (GW) of new coal capacity by 2030 while retiring only three gigawatts of old capacity.

Source: Energy Information Administration. 2008. *Annual energy outlook 2008.*

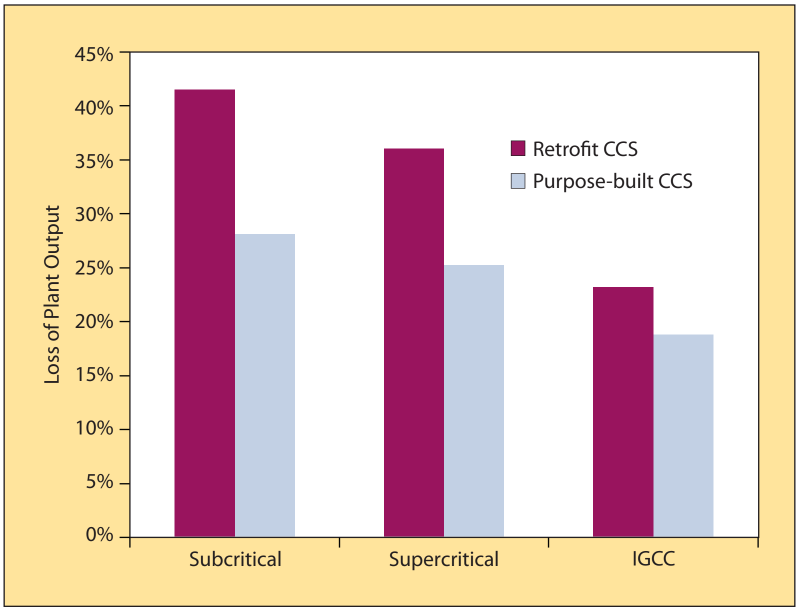
millions of tons of additional CO_2 during a time when we need to dramatically reduce such emissions.

Moreover, even if a new coal plant did replace an older one, it would still represent a costly, long-term commitment to an energy technology with substantially higher CO_2 emissions than any non-coal option. New coal plants are extraordinarily expensive (construction costs have risen 30 to 80 percent since 2004),[104] take years to build (most proposed plants would not begin operating until 2013 or later), and require decades of operation to return the massive capital investment. Locking in such high emissions for so long cannot be reconciled with the sustained emissions cuts we must achieve to avoid the worst consequences of global warming. And, as we discuss below, these new plants are simply not necessary given the cleaner options available to us.

BUILD NOW/RETROFIT LATER IS A DANGEROUS STRATEGY

The MIT report cited earlier shows that the cost and energy penalties associated with adding CCS technology to a coal plant (which are considerable even when the technology is incorporated into the plant's original design) increase substantially for a plant that was not designed to accommodate it.

FIGURE 19: **Added Loss of Plant Output from Carbon Capture Retrofits**



The carbon capture process is expected to reduce the electrical output from retrofitted coal plants by an even greater amount than it will reduce output at coal plants that were originally designed to capture carbon.

Source: Massachusetts Institute of Technology. 2007. *The future of coal: Options for a carbon-constrained world.*

This is a particular problem for pulverized coal plants (the great majority of the 114 proposed plants discussed above). The process of capturing CO_2 diverts a large amount of steam from the boiler that would otherwise have been used by the steam turbine to generate power. As a result, the boiler runs at full capacity but the turbine runs well below its most efficient rate. This steam loss "unbalances the rest of the plant so severely," in MIT's words, that the result is an even greater loss of efficiency.[105] Instead of losing 25 to 28 percent of its maximum potential power, as a plant outfitted with CCS at the start would, a plant retrofitted with CCS would lose 36 to 41 percent of its power.[106] This suggests that the cost of energy from the retrofitted plant would rise by considerably more than the 59 percent increase associated with a new plant already equipped with CCS. As a result, the MIT report concludes that, "retrofits are unlikely."[107]

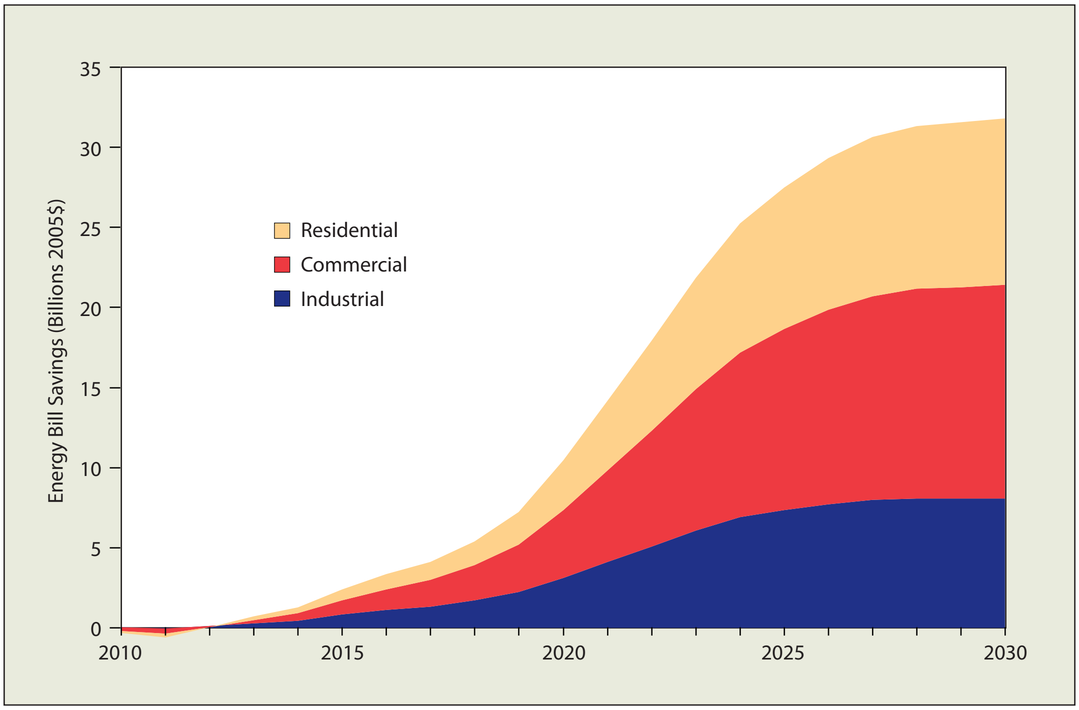
While the retrofit penalty for IGCC plants is expected to be less than for pulverized coal, certain fundamental design features such as the gasifier and gasifier configuration must change if carbon is to be captured. If, for example, the IGCC plant is built with the wrong kind of gasifier, the plant could lose far more of its power when CCS is added than if it had chosen another type of gasifier with CCS in mind.[108] Cost estimates for retrofitting an IGCC plant with CCS are remarkably scarce; the MIT report concluded that there was insufficient information to evaluate most of the available configurations quantitatively.[109]

Another important consideration is the proximity of the plant to an appropriate sequestration site. Many plants have been proposed in locations far from the geologic formations that could store their CO_2;[110] these plants would face considerably higher CO_2 transportation costs (generally by pipeline) than plants in more suitable locations.

Moreover, given the fact that many U.S. coal plant operators have fiercely resisted installing pollution controls for sulfur dioxide (SO_2 "scrubbers"), their assurances that CCS will be added at some future date must be viewed with skepticism. Even though SO_2 scrubbers have been available since the 1980s, only a third of U.S. coal plants have them,[111] and their costs (though relatively high) are likely to pale in comparison to the cost of adding CO_2 capture to a coal plant built without it—especially a pulverized coal plant.

Finally, the failure of a plant's backers to include the cost of a future CCS retrofit in the plant's price tag prevents regulators, ratepayers, and investors from knowing its true cost. It would also be impossible to

FIGURE 20: Cumulative Consumer Energy Bill Savings under a 20 Percent National Renewable Electricity Standard



Under a 20 percent by 2020 national renewable electricity standard, consumers in all sectors of the economy and every region of the country would experience a reduction in their cumulative electricity and natural gas costs of $10.5 billion by 2020 and $31.8 billion by 2030.

Source: Union of Concerned Scientists. 2007. *Cashing in on Clean Energy: A National Renewable Electricity Standard Will Benefit the Economy and the Environment.*

judge how the proposed plant compares with cleaner energy alternatives.

BUILDING COAL PLANTS WITHOUT CCS IS A FINANCIAL AND ENVIRONMENTAL MISTAKE

The fact that so many coal plants have been proposed does not mean they are actually needed to meet U.S. electricity demand. The last time U.S. utilities engaged in a massive campaign to build base-load power plants (i.e., plants designed to operate nearly continuously) was in the late 1960s and 1970s, when the utilities greatly overestimated demand growth and greatly underestimated construction costs (particularly of nuclear plants). The results were often financially disastrous: utilities cancelled 184 proposed power plants, including 80 nuclear plants and 84 coal plants, just in the period from 1974 through 1978.[112] In other cases costly coal plants were built years before they were needed. Under traditional regulation, the power sector is typically allowed to recover all plant construction costs from ratepayers, including an administratively determined return on investment. This gives utilities a financial incentive to build plants whether they are needed or not, and to resist changing course even when circumstances warrant it.[113]

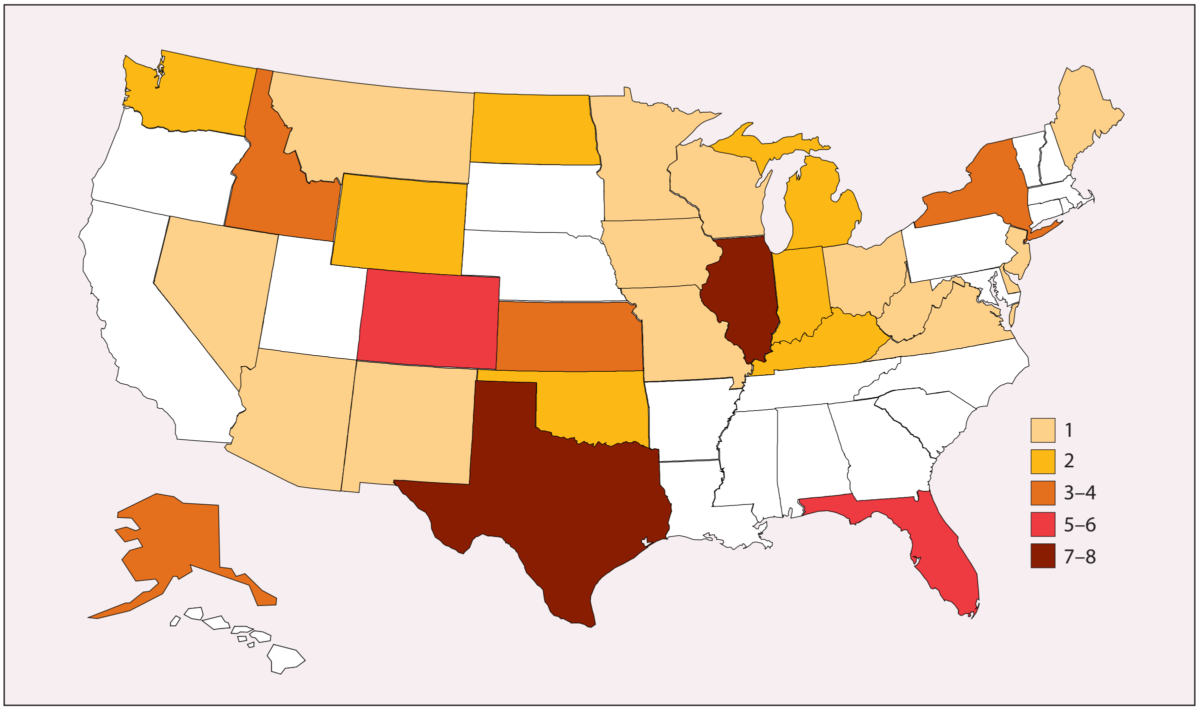
Fortunately, there are commercially available options for avoiding and reducing emissions from coal plants by either reducing electricity demand or substituting low-carbon fuels for coal. Demand can be reduced while meeting energy needs by improving the efficiency with which electricity is produced, transmitted, and consumed. Lower-carbon alternatives to coal include natural gas, renewable resources such as wind, solar, geothermal, bioenergy, and hydropower, and potentially nuclear energy.[114]

Energy efficiency improvements have enormous potential to reduce emissions at a low cost.[115] In addition, our analyses (and those of others) have shown that non-hydroelectric renewable energy supplies in the United States could be increased from about 2.5 percent of electricity use today to 20 or even 25 percent by 2020 or 2025—offsetting much of the projected growth in power plant carbon emissions—without raising consumer energy costs (and in some cases perhaps slightly lowering costs).[116]

Most power producers prevented from building coal plants without CCS will find that their customers' energy needs are better met through increased conservation and efficiency and/or expanded renewable electricity generation. In some cases, additional natural gas generation may also be warranted.

At the same time, states that have adopted new or stricter renewable electricity standards (which require power producers to obtain a specific percentage of

FIGURE 21: Proposed Coal Plants Cancelled or Rejected by Regulators



While more than 60 proposed coal plants have recently been cancelled or rejected by regulators, more than 100 new coal plants are still being proposed by utilities and other companies.

Sources: Sierra Club (*http://www.sierraclub.org/environmentallaw/coal/plantlist.asp*), accessed August 15, 2008. And: SourceWatch (*http://www.sourcewatch.org/index.php?title=Coal_plants_cancelled_in_2007*), accessed July 11, 2008. And: Shuster, E. 2007. Tracking new coal-fired power plants.

their electricity from renewable resources) and energy efficiency standards have found that their once-perceived need for additional coal-fired power has been dramatically reduced. At least 60 coal plant proposals were cancelled, abandoned, or rejected by regulators in 2007, illustrating just how weak the need for such plants is.[117] The DOE's list of proposed coal projects, which included 151 as recently as May 2007, had shrunk to 114 by February 2008.

Increasingly aggressive state efficiency and renewable electricity standards combined with expected federal legislation will further reduce the need to consider new coal plants, buying additional time for CCS technology—and non-coal alternatives—to develop. (We discuss how greater investment in energy efficiency and renewable resources can meet our energy needs for years to come in Chapter 7.) Several large-scale CCS projects are scheduled to become operational in the 2012–2015 range—not much later than the many proposed coal plants without CCS would come into service (2013 or later), though conclusive proof that CO_2 has been safely sequestered would require additional time.

One of the consequences of the current rush to construct coal plants is that many projects are experiencing substantial delays in construction due to shortages of equipment, materials, and specialized labor. The question before the United States is not, therefore, what kind of new coal plants should meet our needs today, because any coal plant will take years to construct. The question is what kind of new coal plants—if any—should meet our needs in the middle of the next decade and beyond, during a period when we need to achieve dramatic emissions reductions.

CCS may or may not prove safe and cost-effective, but there is no justifiable argument for building new coal plants without it. In the event CCS is shown to be unsafe or too costly, the act of building new coal plants will have locked us into decades of higher CO_2 emissions and the much more difficult and costly challenge of reducing emissions by replacing these plants with cleaner alternatives. If, on the other hand, CCS is shown to be a viable solution, coal plants built with the technology will enable us to pursue emissions reductions far more cost-effectively than plants that would have to be retrofitted with CCS.

Clearly, as long as there is no financial penalty for emitting CO_2 and no requirement for new coal plants to be built with carbon capture, power producers have a strong economic disincentive to build such plants.

As a result, while a number of coal projects involving CCS have been announced (see Appendix A), many appear unlikely to proceed without a change in U.S. climate policy. Barring the construction of coal plants without CCS would greatly accelerate the speed at which the technology is developed, and bring us closer to having the necessary information to determine whether it is something we can and should widely deploy.

However, such a policy alone would do nothing to reduce emissions from existing plants, and a policy that sets a high bar for new plants would create an incentive to keep older, inefficient plants operating longer. A requirement that new coal plants capture CO_2 must therefore be combined with policies that drive emissions reductions in the existing fleet. At the very least these policies should include a system for putting a price on carbon emissions, such as a cap-and-trade program (see Chapter 9).

A STRONG PERFORMANCE STANDARD FOR NEW COAL PLANTS IS NEEDED

One promising policy mechanism for preventing the construction of new coal plants without CCS is a CO_2 performance standard, which imposes a limit on how much CO_2 a new coal plant could emit per megawatt-hour (MWh). Such standards have already been adopted in both California and Washington State and proposed in several bills before the 110th Congress. A federal standard at least as strict as California's and Washington's should be enacted and immediately applied to all coal plants commencing construction in the next five years; a more stringent standard should be applied to plants commencing construction after that time.

The current California standard requires that all new base-load power plants emit CO_2 at a rate no higher than combined-cycle natural gas plants.[118] Though the best new combined-cycle plants may emit as little as 800 lb. of CO_2 per MWh, the California Public Utilities Commission set the state standard at 1,100 lb. per MWh to reflect the higher emissions rates of some existing combined-cycle plants.[119] Washington followed suit.[120]

Four federal proposals would also establish performance standards linked to the performance of natural gas plants. Two would limit emissions at the same level as California (one permanently and one as an interim measure);[121] the other two, because they would be modeled specifically on the performance of new combined-cycle plants, would be somewhat stricter than California's standard.[122]

A standard of 1,100 lb. per MWh could be met by a coal plant using far less than complete carbon capture. For example, the most efficient new coal plants, which emit 1,735 to 1,950 lb. per MWh without CCS, could meet the standard with a net capture rate (that is, after factoring in the added coal needed to power the capture process) between 37 and 44 percent.[123] However, CCS has the potential to reduce emissions by a significantly greater degree. The IPCC has estimated that CCS could provide an 80 to 90 percent reduction in CO_2 per unit of energy.[124] This would enable compliance with far more stringent performance standards—in the range of 190 to 380 lb. per MWh (assuming a relatively efficient plant that emits 1,900 lb. per MWh before capture).

Some current federal proposals would set standards in this range: S. 1227 (Kerry; Clean Coal Act of 2007) and the second phase of S.1177 (Carper) call for a 285 lb. per MWh standard. S.309 (Sanders-Boxer), which is discussed in more detail below, would require coal plant operators to obtain an increasing percentage of their power from plants that meet a standard of 250 lb. per MWh.

CCS technology integrated with a large coal plant has yet to be commercially demonstrated, and strict application of a standard that demands net capture rates of 80 to 90 percent immediately could inhibit the technology's development. The 5 to 10 federally supported demonstration projects we recommend should be designed to achieve capture rates of 80 to 90 percent (or the maximum rate feasible for the technology being tested), but as demonstration projects should not be penalized if the technology fails to achieve those rates.

Few (if any) coal plants with CCS are likely to be built in the next few years other than demonstration projects, due to the higher costs and risks associated with early adoption, the uncertainty about when the federal government will put a price on CO_2 emissions, and the availability of safer and less expensive low-carbon alternatives (e.g., energy efficiency, renewable energy). Utilities and others that are already considering CCS projects are likely to seek funding through a federal demonstration program, but any projects that commence construction outside such a program within the next five years should be required to apply CCS to the full emissions stream (rather than allowing part of their flue gases to bypass the capture process, as some projects propose), and to meet a performance standard of at least 1,100 lb. per MWh.

Projects commencing construction after 2013—when we would expect to know the results of the first demonstration projects—should be required to meet a performance standard that reflects the technology's maximum achievable capture rate (currently estimated to be between 80 and 90 percent on a MWh basis). Given coal plants' long operating lives and the critical need to reduce their emissions as deeply as possible in the decades ahead, any long-term performance standard should be based on what the given CCS technology is capable of achieving, not on what natural gas plants emit. A new coal plant that captures 40 to 65 percent of its CO_2 would still represent a large source of new emissions, and because such a plant would likely require far more capital than a comparable natural gas plant, its construction would lock us in to these emissions for a much longer time.

Since new coal plants would be intended to operate well into the carbon-constrained century ahead, it is not unreasonable to require them to emit less CO_2 than a natural gas plant. Setting a performance standard based on what the given control technology can achieve rather than the performance of a competing energy source is a cornerstone principle embodied in the federal Clean Air Act New Source Review and New Source Performance Standards. And as the price of CCS technology gradually falls, it may even be reasonable to require it at new natural gas plants as well as coal plants. CCS is already being investigated at gas plants in Europe.[125]

Any CO_2 performance standard must be paired with a strong cap-and-trade policy (see Chapter 9). Because the performance standard would only apply to new plants and does nothing to reduce emissions from existing plants, a cap-and-trade program that applies to both new and existing plants would ensure that overall emissions are reduced. By the same token, a cap-and-trade program is no substitute for a performance standard. While such a program would discourage the construction of some of the new coal plants that have been proposed, existing flaws in the energy markets (such as the possibility that the cost of future CO_2 allowances may be passed through to ratepayers) make a performance standard necessary to avoid locking the United States in to decades of high emissions from new coal plants already in the pipeline.

RECOMMENDATIONS ON COAL PLANT CONSTRUCTION

The United States should prevent the construction of coal plants that do not employ CCS technology by pursuing the following policies:

- Enact a CO_2 performance standard that requires plants commencing construction between now and 2013 to add CCS to their full emissions stream and achieve a CO_2 emissions rate of 1,100 lb. per MWh or lower.
- Enact a stricter standard that requires plants commencing construction *after* 2013 to meet an emissions limit that reflects maximum achievable capture rates (currently estimated to be 80 to 90 percent on a MWh basis).

CHAPTER FIVE

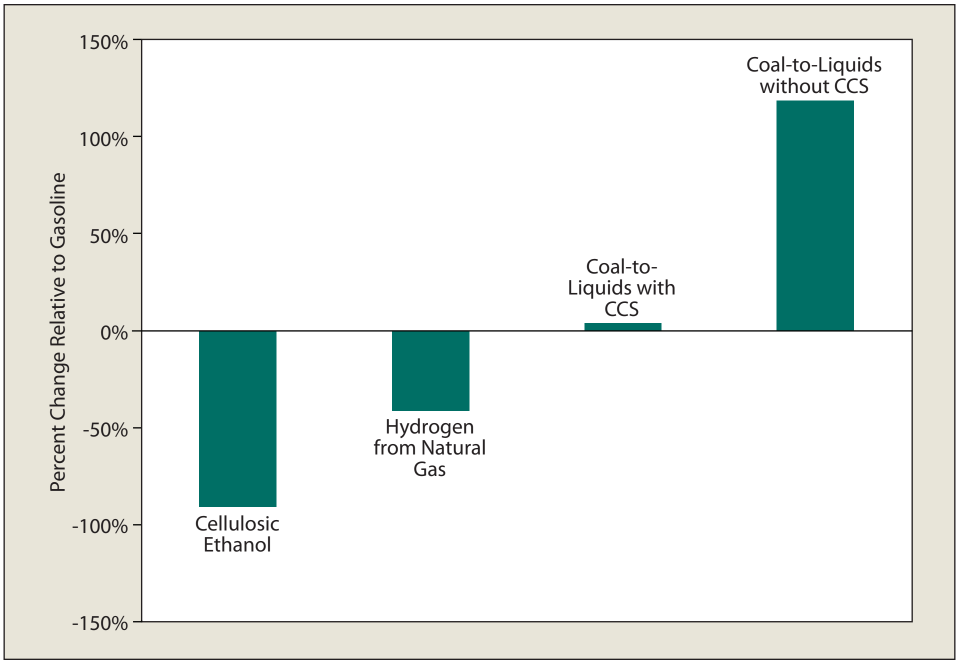
The United States Should Not Support Coal-to-Liquid Technology

Coal-to-liquid technology uses gasification technology and chemical catalysts to make synthetic fuels (often called "liquid coal") that can replace petroleum-based transportation fuels, especially diesel and jet fuels. Over its full life cycle, however, liquid coal produces roughly double the CO_2 emissions of gasoline. CCS can reduce emissions during production, but because emissions from vehicle tailpipes cannot be captured, liquid coal with even the most aggressive CCS possible will still result in life cycle emissions at least as high as conventional petroleum fuels.[126] Liquid coal therefore has no potential to reduce global warming pollution relative to petroleum-based fuels—but it does have the potential to significantly *increase* global warming pollution if CCS is not applied aggressively and effectively.

A much better option would be to use the same process (gasification and catalysts) to create transportation fuels from non-food biomass.[127] Because the carbon in biomass was recently absorbed from the atmosphere through the process of photosynthesis, biomass-based fuels have the potential to greatly reduce life cycle emissions relative to petroleum-based alternatives—as long as biomass production avoids substantial releases of CO_2 from direct or indirect changes in land use.[128] If this is done and CCS is successfully applied during production, biomass-based fuels can become a carbon sink (i.e., removing more carbon from the atmosphere during production than is emitted during combustion).

Because the processes of converting biomass and coal into liquid fuels employ similar technology, the two can also be processed together to create a fuel referred

FIGURE 22: Life Cycle Global Warming Impact of Liquid Fuels Relative to Gasoline



While cellulosic ethanol and hydrogen derived from natural gas have the potential to dramatically reduce global warming pollution over the entire fuel cycle compared with gasoline, coal-to-liquid (CTL) fuel would more than double life cycle emissions if CCS is not employed. Even if CCS *were* employed, CTL's life cycle emissions would still be higher than gasoline's. (Estimate of cellulosic ethanol life cycle impact assumes fuels are made from forest residues and cause no significant changes in land use; if feedstock production leads to deforestation or other damaging changes in land use, life cycle benefits will be lower.)

Source: Environmental Protection Agency. 2007. *Greenhouse gas impacts of expanded renewable and alternative fuel use.*

to as coal-and-biomass-to-liquid (CBTL). But this option does not alter the fact that the best biomass-based fuels have substantially lower emissions than petroleum, while liquid coal can only hope to achieve parity with petroleum. Processing coal and biomass together simply dilutes the potential emissions benefits of biomass-based fuels.

A truly serious strategy for reducing global warming pollution from the transportation sector would regulate emissions from *all* transportation fuels. A low-carbon fuel standard, for example, should require fuel producers to reduce emissions (on an average and energy-equivalent basis) from all the fuels they produce, but leave it to the market to determine the most cost-effective means of achieving these reductions. In addition, this standard should be based on the full life cycle of the fuel, promoting carbon reductions at every link in the supply chain.

A low-carbon fuel standard should be accompanied by safeguards to prevent excessive water use, water pollution, air pollution, loss of biodiversity, and other harmful impacts (see Chapter 8). Water-intensive coal-to-liquid technology would not only increase the environmental and societal costs associated with the mining and transport of coal, but also exacerbate water supply concerns in the arid western states where most U.S. coal production occurs. China, which has invested heavily in the technology, is now facing production constraints because of limited water supplies.[129]

A low-carbon fuel standard with appropriate safeguards for the environment and public health would recognize and reward the potential of biomass-based fuels that are produced in a sustainable manner and supplemented with CCS. In contrast, liquid coal and other high-carbon fuels would be held accountable for their dangerous emissions and fuel cycle impacts.

RECOMMENDATIONS ON TRANSPORTATION FUELS

- All transportation fuels should be held to a low-carbon performance standard that limits global warming pollution and provides safeguards against other environmental damage.
- Neither the federal nor state governments should subsidize or provide any other form of support for coal-to-liquid technology.

CHAPTER SIX

Coal-to-Gas Technology Could Reduce Emissions If It Displaces Other Uses of Coal

Coal can also be converted into a synthetic form of natural gas, but whereas natural gas emits less CO_2 than every other fossil fuel, coal-to-gas technology produces large quantities of CO_2 that, if vented to the atmosphere, would approximately double the emissions of natural gas.[130]

CCS could considerably reduce emissions during the production of coal-based gas, but there is no way to capture the CO_2 emitted at the point of consumption. Therefore, a coal-to-gas plant with CCS that supplies a gas-fired power plant will produce substantially less emissions than a coal plant without carbon capture, but substantially more than a coal plant with full carbon capture.

A startup company called GreatPoint Energy claims to have a new gasification technology that can create synthetic gas from coal (or petcoke or biomass) at a much lower cost than existing technologies.[131] Its process reportedly creates a stream of pure CO_2 as a by-product, so an additional separation process is not required. The company's data show that the carbon footprint for electricity produced using its synthetic gas (and employing CCS) is larger than a natural gas plant but much smaller than a traditional coal plant.[132]

Gasification technology proven to be relatively cost-effective at commercial scale and used to displace existing coal power (not natural gas) could represent a bridge between the high emissions of today's power sector and low-carbon, non-coal power in the decades ahead. For example, coal-derived gas could be sent to natural gas power plants through existing pipelines, reducing demand for electricity from coal plants. A number of newer natural gas plants are not operating at full capacity due to the recent spike in natural gas prices, so coal gasification could allow these plants to expand operations, leading to a net reduction in power-sector emissions if power from coal plants is displaced.

This technology could also allow for the testing of carbon sequestration technologies sooner and less expensively than by adding CCS to IGCC or pulverized coal plants. On the other hand, coal-to-gas technology (as with coal-to-liquid) would increase the environmental costs associated with coal mining and transportation, though this would be offset if coal-to-gas displaced traditional coal combustion. The technology warrants additional analysis to determine the extent to which it could help reduce future emissions.

RECOMMENDATIONS ON COAL-TO-GAS TECHNOLOGY

- Commercial-scale facilities that convert coal into a synthetic form of natural gas must be equipped with CCS.
- Coal-derived gas should replace other forms of energy derived from coal, not natural gas. Regulations or other mechanisms must be developed to ensure that this technology leads to CO_2 reductions, not increases.

CHAPTER SEVEN

The United States Should Direct More Dollars to Efficiency and Renewable Energy

While determining what role CCS can play in the nation's energy future, the United States can meet its growing electricity demand cleanly and cost-effectively by increasing investments in energy efficiency and renewable power. We have already shown how these technologies can help the United States not only avoid the need for new coal plants but also dramatically reduce the use of both natural gas and coal—allowing 181 older coal plants to be retired while saving consumers billions of dollars every year.[133]

THE POWER SECTOR SHOULD BE REQUIRED TO MORE AGGRESSIVELY DEPLOY CLEAN TECHNOLOGY

Blocking the construction of new coal plants without CCS would likely steer additional utility investment toward renewable power and energy efficiency, but not necessarily to the extent it should. Experience shows that utilities are reluctant to invest even in proven technologies that they have not already used. Renewable electricity standards and other policies can help utilities overcome this reluctance.

Renewable energy projects are typically smaller than conventional power plants and consist of components that can be mass-produced, making it easier to achieve economies of scale that will reduce costs and make renewable power more competitive with traditional projects. Renewable power also enhances energy security and price stability by diversifying our energy supply with resources that are not subject to short-term price volatility or long-term price increases.

Unfortunately, energy efficiency faces particularly strong barriers to expansion. Because utilities earn their income (and privately owned utilities make their profit) by selling electricity, conservation and efficiency programs cut into that income (unless state policies compensate utilities for this lost income). State and federal policies must therefore require utilities to expand their energy efficiency programs while reducing their retail energy sales by a specified amount. This is one of the most cost-effective ways we can meet our energy needs and reduce CO_2 emissions at the same time.

As states adopt more and stricter laws requiring utilities to pursue energy efficiency and renewable energy, some utilities that until recently thought additional coal generation was needed have found that is no longer the case.[134] Increased federal efficiency requirements and a federal renewable electricity standard would increase utilities' ability to meet our energy needs without new coal plants.

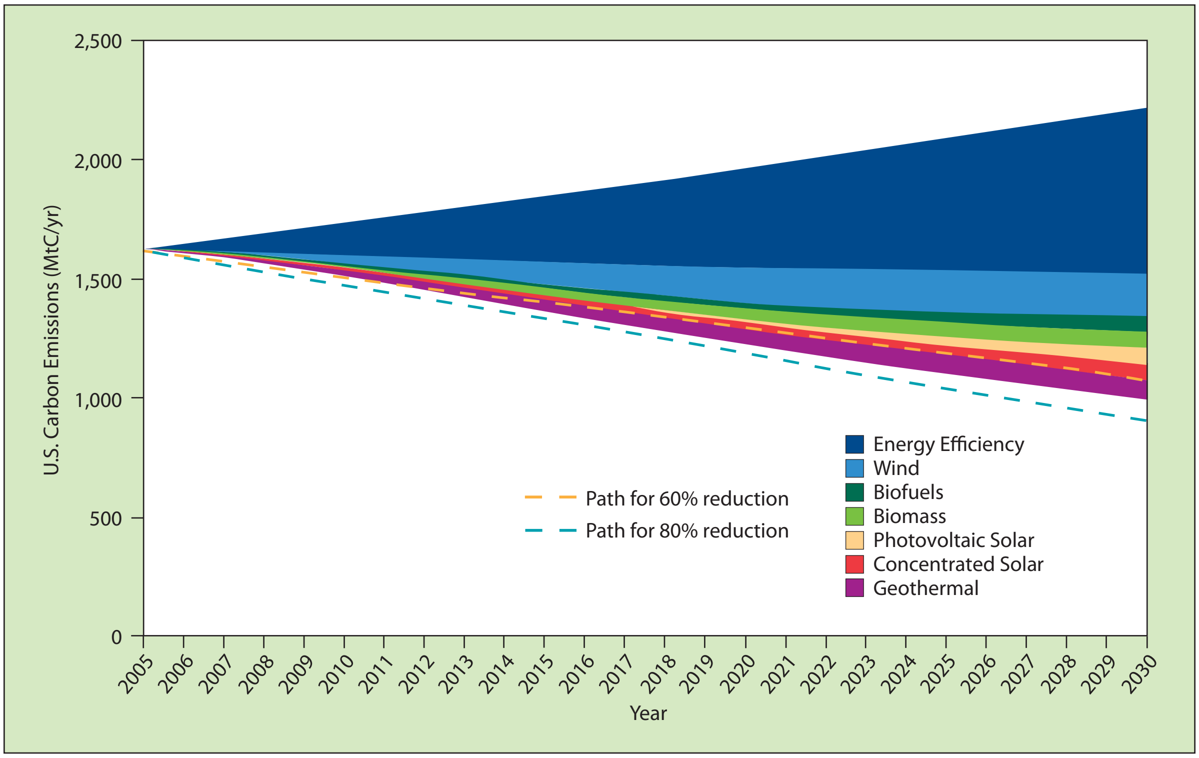
MORE FEDERAL R&D FUNDING IS NEEDED TO ENSURE OTHER TECHNOLOGIES CAN COMPETE FAIRLY WITH COAL

One of the greatest risks associated with pursuing CCS is that it will prevent the nation from giving appropriate attention to truly clean and sustainable energy options (wind, concentrated solar, photovoltaic solar, geothermal, tidal power, biomass, and biofuels) and the myriad emerging technologies that can make us more efficient in our use of energy. A recent study by the American Solar Energy Society (ASES) projected that the United States could obtain virtually all the CO_2 reductions needed up to 2030 by aggressively pursuing energy efficiency and renewable power.[135] The option with the greatest potential by far was energy efficiency (Figure 23).

In addition, the ASES study confirms our own analysis that shows the United States can meet its energy needs and reduce emissions without relying on CCS, at least through 2030. And because it did not look at all renewable options or energy storage technologies, the ASES could well have underestimated the reductions possible with renewable energy.

On the other hand, the ASES study did not examine the costs of its chosen scenario, did not consider

FIGURE 23: **Potential CO_2 Emissions Reductions from Energy Efficiency and Renewable Technologies**



A combination of energy efficiency and renewable energy technologies could bring about emissions reductions by 2030 on the scale needed to achieve 60 to 80 percent reductions by 2050.

Source: American Solar Energy Society. 2007. *Tackling climate change in the U.S: Potential carbon emissions reductions from energy efficiency and renewable energy by 2030.*

whether coal with CCS could play a cost-effective role in reducing emissions, and did not look beyond 2030. It is possible that we may not be able to continue expanding energy efficiency and renewable energy at the same rate beyond 2030. The public may not accept further penetration of renewable technologies, raising the cost of finding suitable sites, and intermittent resources such as solar and wind energy would likely require additional storage beyond 20 percent penetration, with costs that are highly uncertain at this time.

However, a recent analysis by MIT compared the costs of CCS and energy efficiency and projected which energy technologies would meet global needs through 2050. While MIT strongly supports the development of CCS, its modeling showed that the world would save far more energy through efficiency measures than it would obtain from coal plants with CCS.[136]

The development of energy efficiency and renewable energy technologies has been impeded over the years by the difficulty of competing with artificially inexpensive coal power (whose price does not fully reflect the enormous environmental and societal costs associated with its use). Devoting a disproportionate share of federal R&D funding to CCS could accelerate the speed at which this technology evolves relative to cleaner options, further inhibiting the development and deployment of energy efficiency and renewable power. Given the high stakes involved in combating global warming, we should not reduce R&D investment in coal with CCS but rather greatly expand R&D investment in efficiency and renewable technologies.

The federal government's bias in favor of R&D for coal and nuclear power was illustrated in a recent report by the Government Accountability Office (GAO). The GAO analyzed six years of electricity-related R&D (2002 through 2007) and found that nuclear energy received $6.2 billion in R&D funds, fossil fuels received $3.1 billion (almost all of which went to coal-related programs), and renewable energy received $1.4 billion.

The GAO also looked at electricity-related tax expenditures (defined as favorable tax treatment such as tax credits). It found that fossil fuels received $13.7 billion in tax expenditures during the five-year period, while renewable energy received $2.8 billion.[137] The GAO did not quantify other forms of subsidies such as low-income loans provided by the Rural Utilities Service, which have funded many coal plants owned by rural cooperatives (though in March 2008 the U.S. Department of Agriculture announced it was suspending this loan program through fiscal year 2009).[138]

The DOE not only underfunds renewable energy technologies, but also largely ignores energy storage technology. Improved storage options including batteries, thermal storage, and compressed air storage could greatly expand our use of intermittent renewable resources such as wind and solar energy, and should be the subject of aggressive research. If we could cost-effectively store the energy produced from renewable resources for just a few days, we could avoid having to store the CO_2 produced by coal plants—yet the attention paid to energy storage pales in comparison with CCS.

Considering the fact that global warming was recognized as a "serious threat to America's national security" in a recent report by a panel of retired generals and admirals,[139] it is a bit shocking to compare the amount our federal government spends on energy R&D of *any* kind ($1.6 billion in fiscal year 2007) with that spent on defense-related R&D (more than $82 billion).[140] Clearly, cleaner energy technologies are not receiving anything like the level of R&D investment they should receive given the profound nature of the threat we face. Investment in technologies that can reduce CO_2 emissions should be greatly expanded, with the amount based on each technology's relative potential to reduce emissions safely—not on the relative strength of the industry most invested in it. Based on that criterion, renewable power and energy efficiency should receive more funding than coal with CCS.

Launching the accelerated CCS demonstration program we support above, which could easily cost $10 billion over the next few years, will deepen the federal government's bias toward coal-related R&D unless we greatly multiply the funding devoted to cleaner options. A future heavily dependent on CCS may not be the optimal scenario for achieving the deep and rapid emissions reductions we need to protect our climate (and coal use results in other serious environmental and societal costs). If investing in CCS prevents the rapid development of more promising technologies, this strategy would actually handicap our ability to fight global warming. The United States must therefore invest commensurate amounts in various energy efficiency, renewable energy, and energy storage technologies.

Given the fact that global warming is one of the greatest threats humanity has ever faced, investing about $10 billion in R&D and demonstrations of *each* technology that shows promise for reducing CO_2 (including CCS) would not be an unreasonable response. At the very least, each of the efficiency, renewable, and energy storage technologies that have the potential to reduce emissions on the same scale as CCS should receive funding commensurate with CCS.

RECOMMENDATIONS ON ENERGY INVESTMENTS

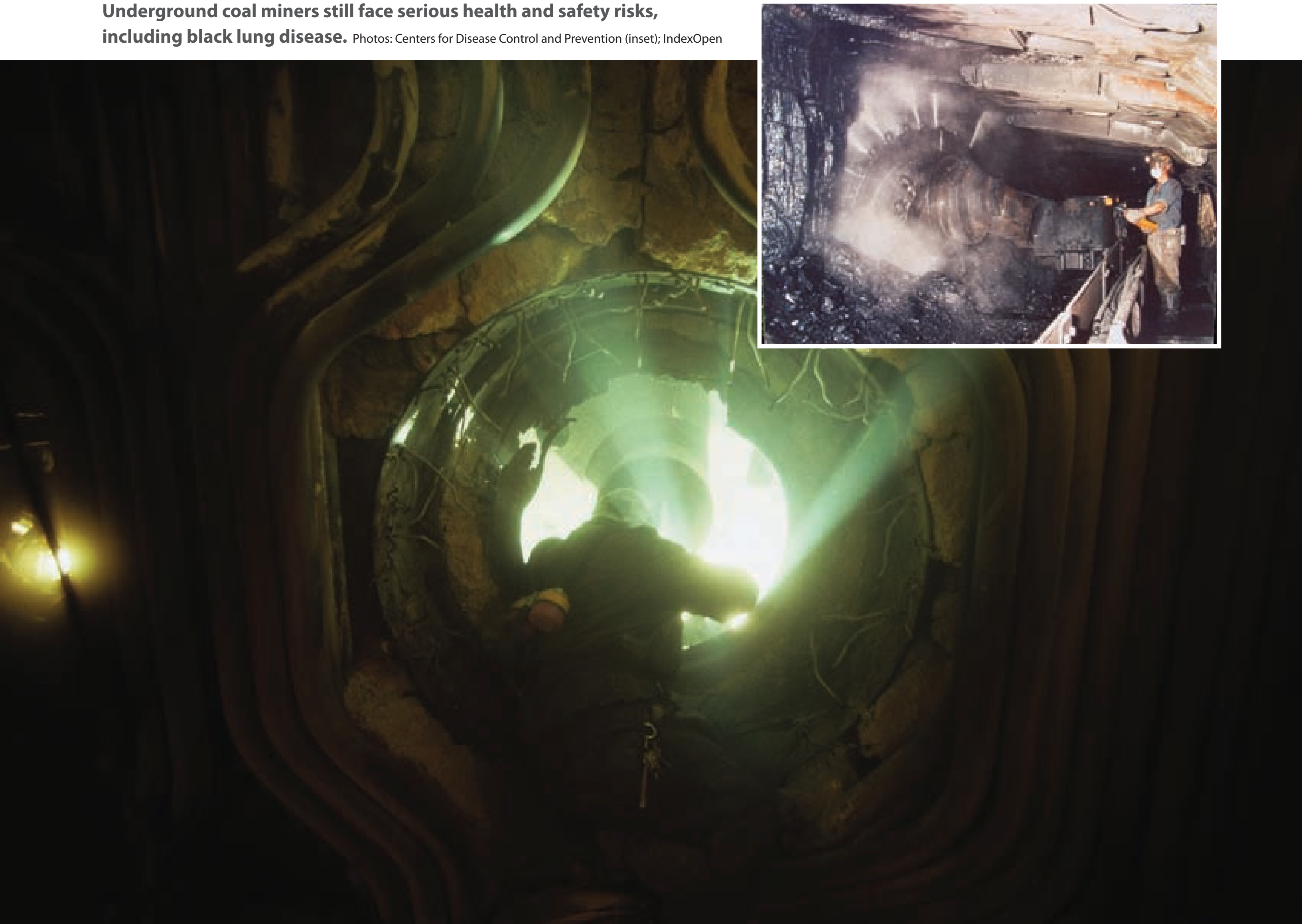
- State and federal governments should immediately adopt policies requiring the power sector to increase its investment in renewable energy and energy efficiency. These policies should include new or stronger renewable electricity standards (which require utilities to obtain a growing percentage of their power from renewable sources) along with energy efficiency requirements and appliance efficiency standards aimed at reducing retail energy demand by a growing percentage each year.
- The federal government should provide far more R&D and demonstration funding for energy efficiency, concentrated solar, photovoltaic solar, geothermal, wind, tidal, biomass, biofuel, and energy storage technologies. This funding should reflect the scale and urgency of the threat posed by global warming, and should be allocated based on each technology's potential to reduce emissions without harming the environment or public health.

CHAPTER EIGHT

The U.S. Coal and Power Industries Must Address the Damage Caused by Coal throughout Its Fuel Cycle

Coal has traditionally been a low-cost source of power only because the environmental and human costs incurred throughout its fuel cycle have never been reflected in the price. As we transform our energy infrastructure in response to global warming and decide how much to invest in coal plants with CCS versus other options, we must keep the full environmental and human costs of coal in mind. Some of these costs may decrease as we implement CCS (which will reduce other air pollutants along with CO_2), but others are likely to increase

Underground coal miners still face serious health and safety risks, including black lung disease. Photos: Centers for Disease Control and Prevention (inset); IndexOpen



because more coal must be mined and burned to generate the same amount of electricity at a plant equipped with CCS as at one without it.

The United States should take steps to reduce these fuel cycle costs wherever possible, and ensure that any remaining costs are reflected in the price of coal power. Costs that warrant particularly serious consideration as we debate the future of coal are mountaintop removal mining, mine waste impoundments (or "slurry ponds"), coal miner safety, and air pollutants other than CO_2 that are emitted by coal plants (see Appendix B).

In addition, enforcement of existing regulations must be greatly improved, not only for inherent health, safety, and fairness concerns, but also to put coal on a more level playing field with resources that do not have comparable fuel cycle impacts. This would also demonstrate that regulation of current activities can be managed effectively before adding the enormous task of regulating carbon sequestration.

RECOMMENDATIONS ON ENVIRONMENTAL AND SOCIETAL COSTS

In addition to stricter enforcement of the many laws governing coal mining and combustion (e.g., the Coal Mine Health and Safety Act, the Surface Mining Control and Reclamation Act, the Clean Water Act, the Clean Air Act), the United States should:

- Enact a statute explicitly banning mountaintop removal mining. No surface mining practice that removes the tops of mountains or buries streams or valleys can be rendered sustainable, since by definition it profoundly changes the landscape in a way that reduces biodiversity and depletes forest and stream resources.
- Ensure that mine waste impoundments are rendered safe and environmentally secure. Mine operators should be required to use best practices to minimize the quantity and toxicity of mine waste, and to construct new impoundments according to stringent safety standards. Existing impoundments should be subject to aggressive regulatory oversight (including inspections to identify safety or environmental risks such as inadequate dam construction, proximity to underground mines, and leakage of contaminants into groundwater).
- Increase R&D funding for strategies to reduce the environmental and societal costs of coal mining and use throughout its fuel cycle, including mining accidents and mine waste management.
- If coal use declines as a result of federal climate policy, provide coal-producing areas with eco-no-mic assistance that would be funded by a specific share of the proceeds from cap-and-trade auctions.
- Require coal mine and power plant operators to pay into a fund created to clean up the environmental and societal damage caused by coal over the decades (which, in turn, will encourage the industry to build these costs into the price of coal).
- Require coal plant operators to use the "maximum achievable control technology" (the highest pollution control standard under the Clean Air Act) to reduce emissions of mercury and other toxic pollutants from new and existing plants.
- Require existing coal plants to further reduce emissions of sulfur dioxide, nitrogen oxides, and particulate matter.
- When permitting new coal plants, require that the environmental impact statement covers the full fuel cycle, including upstream impacts (from mining, fuel treatment, and transport) and downstream impacts (from waste disposal).

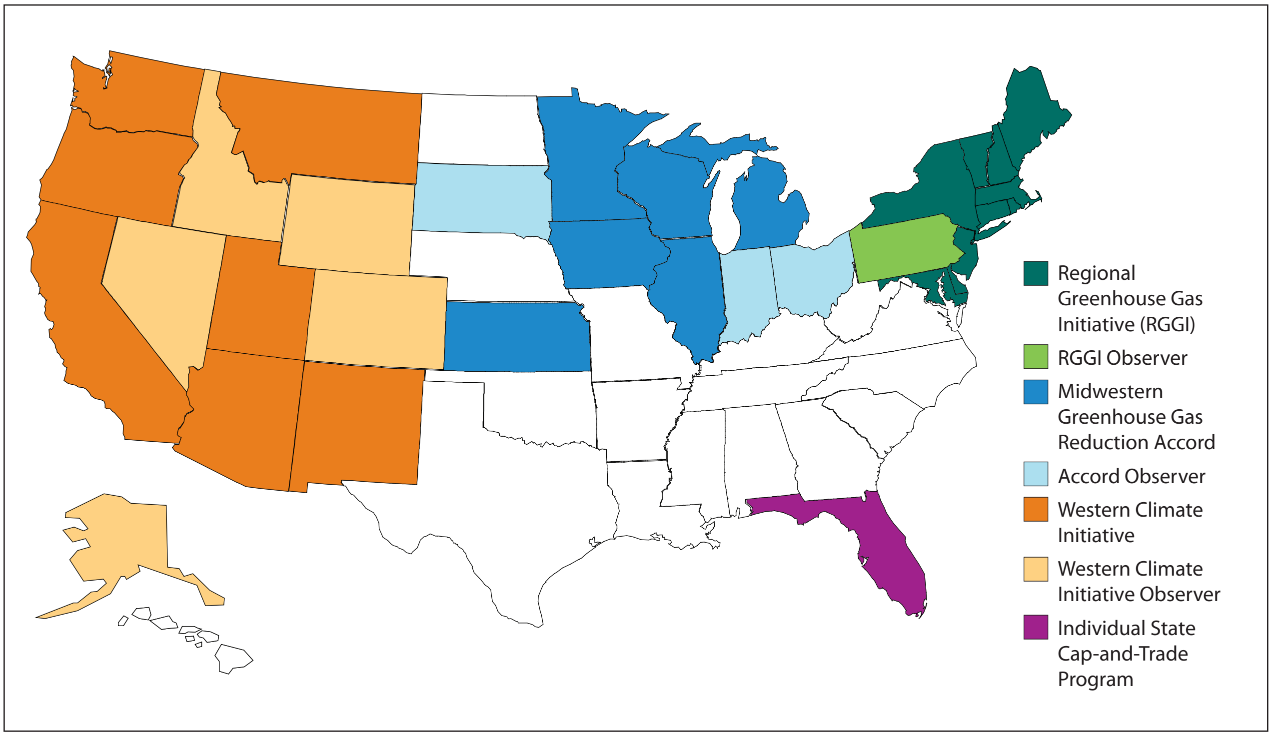
CHAPTER NINE

The United States Should Adopt a Strong Cap-and-Trade Policy

Requiring new coal plants to capture their global warming pollution will not drive reductions from the existing coal fleet. The federal government should therefore adopt a cap-and-trade policy that puts a cap on total emissions, creates an ongoing financial incentive to reduce emissions by establishing a price on each ton of CO_2 emitted, and allows power plant operators to trade pollution allowances. Such a program should complement other policies that can reduce emissions more cost-effectively than cap-and-trade alone.

Most observers expect the United States to adopt some type of cap-and-trade policy in the next few years that will cap global warming pollution from multiple economic sectors (or at the very least from the power sector) and require polluters to own enough government-issued but market-tradable allowances to cover each ton of CO_2. Many states are already setting up regional cap-and-trade agreements, including the 10 states participating in the Northeast Regional Greenhouse Gas Initiative (RGGI), the seven states participating in the Western Climate Initiative (WCI), and the six states that have begun a similar initiative in the

FIGURE 24: **Regional Cap-and-Trade Markets**



Twenty-three states in the East, West, and Midwest have agreed to form regional CO_2 cap-and-trade markets. Another eight states are official observers to these emerging regional markets. Florida regulators have been authorized to develop a cap-and-trade program covering the state's electric utilities.

Source: Pew Center on Global Climate Change. 2008. Regional initiatives. Online at *http://www.pewclimate.org/what_s_being_done/in_the_states/regional_initiatives.cfm*. Accessed August 28, 2008.

Midwest. In addition, the U.S. Congress is considering several bills that would establish a federal cap-and-trade program. Details aside, such a program must assign a price to emissions in the broader market so that market forces can help drive emissions reductions rather than continue to propel them upward.

Cap-and-trade laws must also set caps low enough to actually drive the dramatic emissions reductions we need. By the same token, cap-and-trade laws cannot allow excessive "offsets," which enable polluters to fund and receive credit for reductions at pollution sources not covered by the cap (rather than reducing their own emissions or purchasing allowances from another source covered by the cap). It is inherently difficult to prove that the reductions claimed by an offset project would not have happened anyway, and more importantly, allowing the power sector to meet the cap by funding reductions in other sectors will inhibit the development of new, low-carbon alternatives to coal power. These newer technologies will be less able to attract capital and commitments because investors will have less certainty about the future market for low-carbon alternatives.

It is also important that cap-and-trade programs auction CO_2 allowances rather than allocating them to polluters for free. Europe's experience with CO_2 cap-and-trade illustrates the mistake of free allocations: power plant operators were given allowances for free and received windfall profits as a result. This is one reason why the RGGI states are moving toward full or nearly full auctioning of their allowances. Even in states that regulate retail electricity rates but allow wholesale competition, windfall profits could still result if allowances were allocated for free.

Giving allowances to coal plant operators would amount to yet another subsidy for coal power, further slowing the needed transition to cleaner technologies. By contrast, auctioning allowances would create a publicly controlled pool of funds that could be used to accelerate the transition to cleaner technologies (through CCS demonstrations, for example) and address any inequities this transition may cause. Rebuilding our energy infrastructure will require a sustained public investment, and auctioning allowances can provide a sustained public revenue stream commensurate to the task.

RECOMMENDATIONS ON CAP-AND-TRADE

- Congress should enact a cap-and-trade law requiring CO_2 reductions of at least 80 percent by 2050, with interim targets that ensure early and sustained reductions. (Until Congress acts, states should continue to develop regional programs with similar targets.) There should be no loopholes in the federal law that would undermine its reduction goals or delay the introduction of clean energy technologies.
- Revenues from the auction of pollution allowances should be used to accelerate and ease the transition to low-carbon energy technologies (e.g., by funding demonstrations of CCS and other carbon-reducing technologies, funding energy efficiency and renewable energy projects, aiding low-income energy consumers, helping workers or communities that may suffer economic losses due to the transition to cleaner technologies). Coal miners and mining communities could face particular hardships if coal use contracts as a result of federal climate policy, in which case auction revenues should be dedicated to miner retraining assistance and economic diversification aid for mining communities.

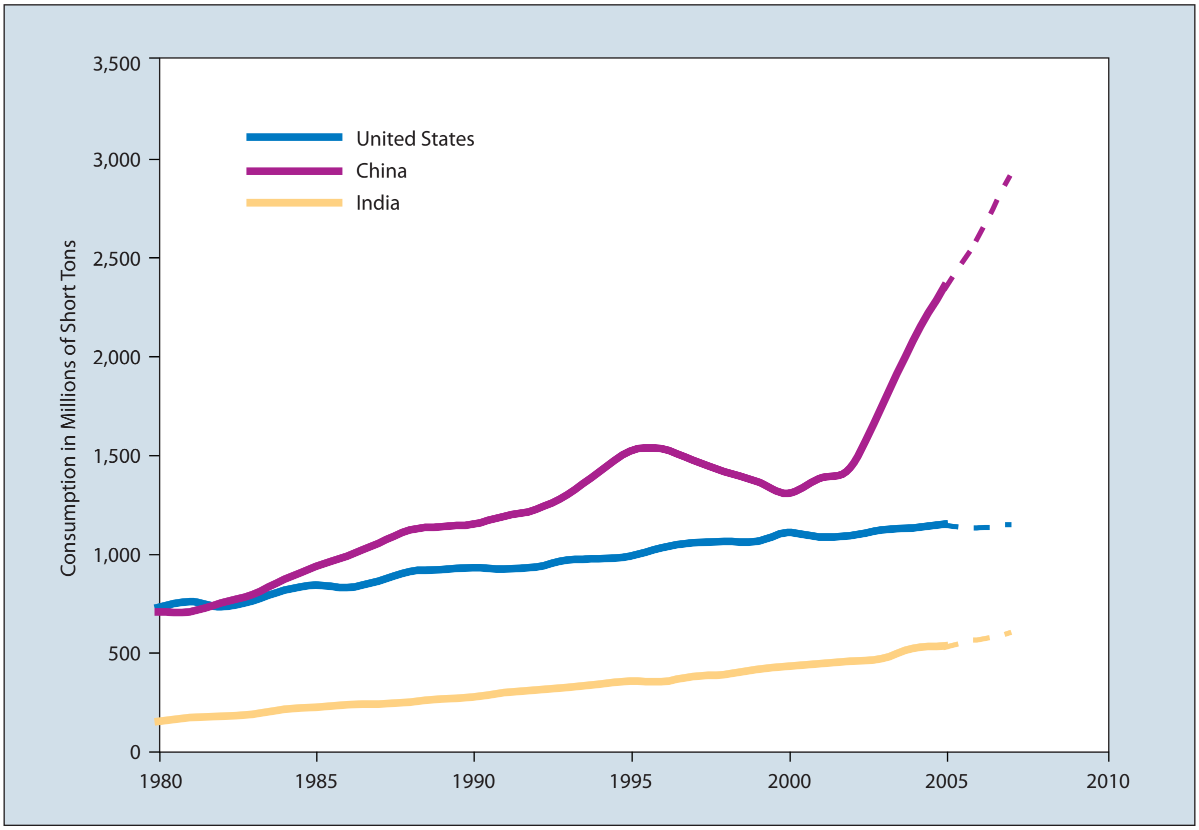
CHAPTER TEN

CCS Demonstration Results Should Be Shared with Developing Nations

As risky as the potential expansion of the U.S. coal industry is, it pales in comparison with expansion in the developing world, especially in China and India. China is reportedly building the equivalent of two new 500 MW conventional coal plants per week,[141] and the country already consumes far more coal than the United States.[142] However, some progress was made in reducing China's global warming pollution in 2007, as the country replaced more than 14 GW of electricity generated by small, inefficient coal plants with electricity generated by mostly larger, more efficient supercritical plants, saving 11 million tons of coal and 30 million tons of CO_2.[143]

Unless developing countries begin aggressive emissions reductions soon, it may become impossible to avoid the worst consequences of global warming regardless of actions taken in developed countries. Our analysis shows that if emissions in the developed world peak in 2010 and are followed by sustained

FIGURE 25: Coal Use in China, India, and the United States



China's use of coal now exceeds that of the United States, and is rising dramatically—China is building the equivalent of two 500 MW coal plants each week.

Source: Energy Information Administration. 2008. International coal consumption. June 26. Online at *www.eia.doe.gov/emeu/international/coalconsumption.html.* The chart uses historical data through 2005 and EIA projections for 2006 and 2007.

and aggressive reductions of at least 80 percent below 2000 levels by 2050, the developing world's emissions will need to peak between 2020 and 2025 (followed by significant reductions).[144] Therefore, coal plants without CCS should not be built in any part of the world.

CCS technology may be essential to emissions reductions in the developing world, especially if China's economy continues to grow so quickly that meeting its electricity demand requires building new power plants of all types. (Manufacturing and construction bottlenecks could make it impossible to keep pace with growing demand through efficiency and renewable energy alone.)

This potential need for CCS in developing countries is further reason for the United States to accelerate its own demonstration program, and to do so at a large enough scale to explore a range of different technological approaches (i.e., the 5 to 10 projects we recommend). Such a program will yield valuable information over the next few years about CCS relative to other options available to both the developed and developing worlds.

Some clean energy advocates have argued that the need to accelerate CCS adoption in China and other developing countries is one reason for a broader and longer-term U.S. commitment to CCS—moving beyond demonstrations to immediate deployment.[145] However, there are potentially serious financial and environmental risks to making such a commitment before the technology has been demonstrated at commercial scale. A more sensible strategy would be to first demonstrate the technology and then, if the demonstrations are successful, deploy it in those countries where it is needed. These demonstrations will help the United States decide which options are most cost-effective and have the fewest risks relative to other technologies.

It has not been proven that rapid deployment of CCS is necessarily the best option for developing countries. Because of limited resources, consumers in these countries tend to purchase equipment with lower initial costs and lower efficiency, which means there are even greater opportunities for improving energy efficiency in developing countries than in the United States.[146] From 1980 to 2000 for example, China showed steady improvement in energy efficiency, as its economy grew twice as fast as its energy consumption.[147] This was a remarkable achievement considering the fact that energy use in most developing countries grows faster than the national economy.

China has also established the world's most aggressive energy efficiency target: a 20 percent reduction in energy consumption per unit of gross domestic product (GDP) between 2005 and 2010.[148] If China can meet this target, it will have reduced its CO_2 emissions (compared with "business-as-usual" projections) by 1.5 billion tons in just five years, greatly exceeding the European Union's commitment under the Kyoto protocol to reduce emissions approximately 300 million tons over a 15-year period. Unfortunately, China's energy consumption per unit of GDP fell only 1.23 percent in 2006—well short of the annual goal of 4 percent—due to a surge in manufacturing and the movement of people from rural to urban areas, which has increased the need for new infrastructure.[149] To counteract these trends and meet its efficiency target, China will have to establish additional government policies and deeper levels of investment.

Renewable energy represents a significant opportunity for all countries, and China and India are already on their way to becoming global leaders in renewable energy development. For example, China has already met its 2010 target of 5,000 MW of electricity from wind power,[150] and a recent study indicates that the country may also surpass its goal of obtaining 15 percent of its total energy and 21 percent of its electricity from renewable resources by 2020.[151] In that amount of time, China's installed capacity from small hydro, wind, biomass, and solar power is expected to reach 137 GW, which represents an investment of nearly $270 billion.[152]

One other factor to consider is that safe and successful CCS demands a thorough and well-funded regulatory system to ensure that sequestration sites are properly selected and monitored, and that power producers continue to comply with capture and storage requirements. This level of oversight will be a challenge in developed nations; it will be even harder in rapidly developing ones. China's regulatory authorities are already so overwhelmed by the flood of new coal plants that many of those being built have never even received construction approval from the government.[153]

Nonetheless, the urgent need to prevent the construction of coal plants without CCS in the developing world will require the United States and other developed nations to transfer CCS technology to developing countries as it evolves. CCS demonstration projects are already under way in Australia, Canada, Europe, and the United States, while China and India are pursuing advanced IGCC and supercritical pul-

China has already met its 2010 target of 5,000 MW of electricity from wind power. Photo: Joe Sullivan

verized coal demonstrations (see Appendix A).[154] The European Union and the United Kingdom are already working with China on CCS research, development, and deployment that will produce a demonstration plant in China by 2020.[155] Technology transfer is also being promoted by the Carbon Sequestration Leadership Forum (CSLF), an international initiative representing both developed and developing nations that seeks "to make these technologies broadly available internationally." [156]

Developed nations must also ensure that international financial institutions provide appropriate support for low-carbon technologies of all kinds, and potentially help pay for emissions reductions in developing countries when doing so is highly cost-effective. Expanding the transfer of clean energy technologies to developing countries and financing their accelerated deployment is a core element of the "Bali action plan" adopted in December 2007 by the parties to the United Nations Framework Convention on Climate Change (including the United States). The plan calls for "nationally appropriate mitigation actions by developing country Parties in the context of sustainable development, supported and enabled by technology, financing and capacity-building, in a measurable, reportable and verifiable manner."[157] The scope and scale of the support to be provided by developed nations, and the criteria for awarding this support, are key issues in the current negotiations on the post-2012 international climate treaty that countries aim to finalize by the end of 2009.

Finally, the World Bank and other international sources of funding should phase out financial support for conventional coal plant construction in developing nations. Continuing to construct coal plants without CCS in the developing world undermines efforts to steer these nations onto a low-carbon path, and will make it harder to reverse their growing emissions in time to avoid the worst effects of global warming.

RECOMMENDATIONS ON INTERNATIONAL ASSISTANCE

The United States should:

- Freely share the technological lessons learned from federally funded CCS demonstration projects with developing countries, and ensure that technology transfer is not hindered by unduly restrictive intellectual property rights.
- Participate in the development of international financing mechanisms that would promote and support the use of CCS (and other low-carbon energy technologies) by developing nations.
- Steer economic aid for developing countries toward technologies that will reduce CO_2 emissions.

CHAPTER ELEVEN

Conclusion

To avoid the worst consequences of global warming, the United States must have a coherent set of policies designed to dramatically reduce CO_2 emissions from coal plants. First, we must immediately stop the construction of coal plants that do not employ CCS technology, so federal policies should include a CO_2 performance standard and a cap-and-trade program that will render coal plants without CCS a financial liability.

Given the significant potential CCS technology has for reducing global warming pollution, the United States should undertake a demonstration program of 5 to 10 commercial-scale CCS projects, which will enable us to determine the technology's merits as quickly as possible. In the meantime, the United States should meet its growing energy needs by more aggressively deploying energy efficiency and renewable energy.

An increased investment in CCS must be accompanied by a dramatic increase in R&D funding for efficiency, renewable power, and energy storage. This will expand our options for responding to climate change and will help ensure that federal R&D funding does not unduly favor coal at the expense of alternatives with lower costs and fewer risks. We cannot yet say whether coal with CCS, other technologies, or a combination of both will emerge as the economically and environmentally preferable long-term option for reducing emissions.

Furthermore, because an increased investment in CCS may expand coal use—and all of the environmental and societal costs associated with its use—the United States must take simultaneous steps to minimize those costs. To that end, the federal government should ban mountaintop removal mining, secure mine waste impoundments, and improve and enforce laws related to mine safety.

Finally, the United States must put a market price on CO_2 emissions by adopting a strong cap-and-trade law designed to ensure the necessary emissions reductions from existing coal plants. Revenues from the auction of pollution allowances can be used to accelerate the transition to cleaner energy technologies and alleviate any financial hardships that may be faced by miners and mining communities as a result.

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APPENDIX A

Status of CCS Technology

There are three components to carbon capture and storage (CCS) as applied to coal-fired power plants: the capture of the carbon dioxide (CO_2) from the coal plant; its transport (almost always by pipeline) to a suitable geologic storage, or sequestration, site such as an oil or gas field or saline aquifer (a formation filled with saltwater not useful as drinking water); and the injection of the CO_2 into that site. This appendix discusses each of these components, but devotes the most attention to carbon capture (which is the mostly costly component) and sequestration (which poses the greatest environmental risk).

The technologies involved in CO_2 capture, transport, and sequestration have all been demonstrated at some level (though new capture technologies are still emerging). However, they have not been demonstrated at anything like the scale contemplated by its backers. Moreover, CCS has not been demonstrated in an integrated form (i.e., with a full-size, commercially operating coal plant at one end and a well-monitored sequestration site at the other).

CO_2 CAPTURE

There are three types of CO_2 capture technology under development today: pre-combustion, post-combustion, and "oxyfuel." The Intergovernmental Panel on Climate Change (IPCC) estimates that available CCS technologies can capture between 85 and 95 percent of the CO_2 from a coal plant, but because this process requires its own source of energy—additional coal consumption—the amount of CO_2 actually avoided per kilowatt-hour of electricity produced would fall to between 80 and 90 percent.[1]

Below we describe specific CCS pilot or demonstration projects that have been announced in each technological category. There are other CCS programs that have not yet announced an actual construction project or determined which technology will be employed; for example, the European Union (EU) aspires to have as many as 12 demonstrations in place by 2015, and a public-private partnership has launched an initiative called the EU Flagship Programme to help achieve that goal.[2] China has launched a program supported by the EU and the United Kingdom (UK) called Near Zero Emission Coal, which intends to construct a coal plant with CCS, but is still considering a range of technologies.[3] And the United States has been supporting research and development (R&D) into CCS for some time, especially through the Department of Energy's National Energy Technology Laboratory (NETL).[4] It should be noted that CCS is also being investigated in contexts other than coal-fired power plants, such as natural gas processing facilities.[5]

In many cases, the proposed projects are waiting for policy changes or subsidies that will make them more cost-effective. As long as CO_2 can be emitted for free, adding CCS substantially increases the cost of energy from coal plants, making it impossible for plants with CCS to compete against new coal plants built without CCS. Even in places where there is already a price applied to CO_2 emissions, such as in the EU, it is generally assumed that the risks and costs associated with CCS demonstrations will prevent such projects from moving forward without government support.

Pre-combustion capture. When integrated gasification combined cycle (IGCC) plants gasify coal, they create a synthetic gas, or "syngas," that contains hydrogen and carbon (mostly in the form of carbon monoxide, CO, but also some CO_2). Using a process called a shift reaction, the CO in the syngas can be shifted to CO_2, which can then be removed before the syngas is burned in a combustion turbine. Because pre-combustion CO_2 is still in a relatively concentrated and high-pressure form, it can be removed at a lower cost than post-combustion processes.

Without employing a shift reaction, some CO_2 can be captured from an IGCC plant by capturing that fraction of the syngas that is already CO_2. This sort of "unshifted" partial carbon capture might capture between 15 and 30 percent of the plant's CO_2.[6]

None of the four IGCC coal plants operating in the world currently employs carbon capture, though the two operating in Europe have announced plans to conduct pilot projects at their facilities.[7] Also, the Dakota Gasification Company operates a coal gasification plant in Beulah, ND, that makes synthetic natural gas (rather than generating electricity) and employs pre-combustion technology to capture about half of its CO_2 emissions. The CO_2 is then transported by pipeline more than 200 miles to Weyburn, SK, where it is pumped into an aging oil field—one of the world's largest carbon sequestration demonstration projects (discussed in more detail below).[8] It is worth noting that the same technologies used in pre-combustion capture are already widely used for the large-scale production of hydrogen in the fertilizer and refining industries.[9]

Commercial-sized IGCC plants that would employ substantial levels of CCS have been announced around the world.[10] The Wallula Energy Resource Center in the state of Washington, for instance, could become the site of a 914-megawatt (MW) facility at which backers have pledged to capture "at least 65%" of its CO_2 (allowing it to meet Washington's CO_2 emissions performance standard) and sequester the carbon in deep basalt formations.[11] A joint venture by BP and Rio Tinto has applied for a permit to construct a 390 MW IGCC plant in California that would mainly use a coal-like petroleum by-product called petroleum coke or "petcoke." The plant would capture 90 percent of its CO_2 for use in enhanced oil recovery (discussed below).[12]

An Australian IGCC/CCS project called ZeroGen is moving forward in two phases, starting with an 80 MW plant scheduled for 2012 and a 300 MW plant scheduled for 2017.[13] The German power company RWE has announced a 360 MW IGCC/CCS plant scheduled to be built in 2015.[14] In the UK, power producer Powerfuel and a Shell subsidiary have announced plans for a 900 MW IGCC/CCS plant that would become operational in 2013.[15] And China is planning an IGCC/CCS project called GreenGen, which would begin as a 250 MW plant and expand to 650 MW in a later phase. Peabody Energy, the largest U.S. coal company, recently joined this initiative.[16]

Of course, the fact that such projects have been announced does not guarantee they will be built, and other announced IGCC/CCS projects have already been cancelled or are being restructured. This includes the high-profile FutureGen project, a now-defunct partnership between the U.S. Department of Energy (DOE) and a consortium of large coal producers and electricity generators. FutureGen was to be this country's flagship CCS demonstration project, involving a 275 MW IGCC plant located in Illinois that would have captured a minimum of 1 million tons of CO_2 per year, or about 90 percent of its emissions.[17] The CO_2 would then have been sequestered in deep saline formations at or near the generation site. The DOE withdrew its support for this project when costs reached $1.8 billion, nearly double the original estimate;[18] however, a restructured FutureGen project has been announced that aims to provide federal funding for the CCS portion of multiple coal plants.[19]

Power producer NRG had announced plans in 2007 to build a 755 MW IGCC plant in New York with 65 percent capture—provided that public subsidies and carbon pricing would make the project commercially viable—but when state officials withdrew their support in 2008, NRG concluded that "the necessary funding was not there" and cancelled the project.[20] BP and Rio Tinto recently cancelled their 500 MW IGCC/CSS Australian project called Kwinana after geologic studies indicated the selected sequestration site was not actually suitable.[21]

Post-combustion capture. Conventional pulverized coal plants can capture their CO_2 only after the coal has been burned, which is more challenging than pre-combustion capture because of the low concentration and low pressure of the CO_2 in the resulting exhaust gases. This is because air, which consists mostly of nitrogen, is used to fuel the combustion and dilutes the CO_2. However, CO_2 can still be captured from a plant's flue gases using chemical processes. So-called amine scrubbers are considered the state-of-the-art technology for this purpose and are widely used in vastly smaller applications than power plants (e.g., to obtain CO_2 for industrial purposes or carbonated beverages). Amine scrubbing uses a great deal of energy, however. Another method using chilled ammonia is being tested to see if it can capture CO_2 using less energy. Partial capture of CO_2 can be achieved by routing just a portion of the flue gases through a capture process.

A few small post-combustion test projects are under way, have recently been completed, or are about to begin. The Esbjerg pulverized coal plant in Denmark, for example, currently routes 0.5 percent of its flue gases (called a slipstream) through amine scrubbers as part of a pilot project supported by the EU.[22] We Energies is testing carbon capture from a slipstream equivalent to 1.7 MW at a Wisconsin pulverized coal plant using chilled ammonia.[23] AEP has announced that it will conduct a larger trial of chilled ammonia capture in 2009, which will be applied to a slipstream representing 20 to 30 MW of its 1,300 MW Mountaineer pulverized coal plant in West Virginia; the captured CO_2 will be sequestered in an onsite saline formation.[24]

Four plants have been announced in North America that would extend CCS technology beyond the pilot phase by adding it to a substantial portion of the emissions from existing pulverized coal plants. First, AEP has announced it will follow up its Mountaineer plant test with a larger one in 2011, on emissions equivalent to 200 MW at its 450 MW Northeastern Station coal plant in Oklahoma. AEP expects to seek DOE funding for this project, which would capture about 1.5 million tons of CO_2 yearly and sequester it in nearby oil fields—with the added objective of enhanced oil recovery (EOR, which is intended to force oil up toward wells that have been declining in productivity).[25]

NRG has announced a CCS test on a 125 MW share of its WA Parish pulverized coal plant in Sugar Land, TX, which would attempt to capture about 1 million tons of CO_2 annually beginning in 2012 and use it for EOR. NRG states that it will "work with government and non-government entities to provide additional funding for the project."[26]

Basin Electric is evaluating proposals for a demonstration project that would capture more than 1 million tons of CO_2 annually from a 120 MW share of its Antelope Valley lignite plant in North Dakota. The plant is to be located next to the Dakota Gasification Company plant that already captures its CO_2, and the two plants would share CO_2 compression equipment and pipelines. Basin Electric has also stressed the need for federal support to make this project viable.[27]

SaskPower, owned by the province of Saskatchewan, has announced plans to proceed with a $1.4 billion (Canadian) project to repower its 130 MW Boundary Dam coal plant. The carbon capture process will reduce the plant's output, resulting in a 100 MW plant that captures about 1 million tons of CO_2 annually and uses the CO_2 for EOR. However, even with a promise of $240 million (Canadian) from the federal government, SaskPower has said it still needs oil industry partners to buy the captured CO_2 for EOR in order to make the project cost-effective.[28]

Outside North America, the Swedish power company Vattenfall has recently announced two major projects that would add CCS to existing coal plants. One would reduce the output of Denmark's Nordjylland plant from 376 to 305 MW by 2013, while capturing 1.8 million metric tons of CO_2 yearly. Vattenfall also plans to add post-combustion capture to 250 MW of the German lignite plant at Janschwalde.[29] The company is already a world leader in investigating CCS with oxyfuel combustion (see below).

New pulverized coal plants with post-combustion capture have also been announced. For example, Tenaska has proposed a $3 billion project near Sweetwater, TX, involving the construction of an approximately 600 MW supercritical coal plant that would capture 90 percent of its CO_2, which would be pumped into the Permian Basin for the purpose of EOR.[30] The company has stated that it will not decide whether to build the plant until 2009, depending on several factors including financial incentives and market prices for carbon emissions.[31]

The UK is holding a competition that will award government funding to support the construction of a commercial-scale coal plant with post-combustion CCS, and has announced four finalists for the subsidy.[32] In addition, a consortium of U.S. power producers and the Electric Power Research Institute (EPRI) has proposed a program called UltraGen that would support the building of two pulverized coal plants with CCS that would come online in 2015 and 2020, respectively. The first would be an 850 MW plant that would run a quarter of its emissions stream through the capture process, followed by a 650 to 700 MW plant that would run half its emissions stream through the capture process. Host sites for these plants are being sought, with the incremental capture costs to be covered by the consortium.[33]

Oxyfuel combustion. If coal is combusted using nearly pure oxygen rather than air, the resulting exhaust is mainly CO_2 and water vapor. The higher concentration of CO_2 lowers the costs of carbon capture (though there are additional costs associated with obtaining the needed oxygen).

A pilot project by Vattenfall to test oxyfuel combustion at a pulverized coal plant is under construction in Germany and scheduled to become operational in September 2008. Vattenfall has also announced an oxyfuel demonstration project at the Janschwalde lignite plant in Germany (where it is also planning a demonstration of more traditional post-combustion capture). The Janschwalde oxyfuel demonstration involves replacing the existing boiler with a 250 MW oxyfuel boiler, and will result in the capture of 1.1 million metric tons of CO_2 yearly.[34]

Smaller oxyfuel pilot projects have been announced in the United States and Australia. The state of New York, for example, is supporting the public/private Oxy-Coal Alliance, which will test oxyfuel combustion by building a 50 MW coal plant with CCS in Jamestown, NY. The project depends on obtaining $100 million in federal funding and the passage of new state laws to regulate CCS.[35] Oxyfuel and CCS are also being tested at a 50 MW natural gas power plant in California, with substantial funding from both the federal and state governments. The plant will capture 1 million tons of CO_2 over four years as part of a sequestration demonstration project.[36] The CO_2 will be sequestered in a geologic formation beneath the plant, with oversight provided by the California Energy Commission and funding from the DOE.[37]

Another oxyfuel/CCS project at a coal plant is under way in Australia. This joint venture among Japanese and Australian companies, with support from the Australian government, will retrofit the Callide-A plant with a 30 MW oxyfuel test by 2010.[38]

SaskPower had previously considered building a 300 MW oxyfueled coal plant with carbon capture but cancelled these plans when the estimated cost reached $3.8 billion (Canadian).[39] As noted above, SaskPower is now pursuing an air-fired post-combustion CCS retrofit project instead.

CO_2 TRANSPORTATION

Most CCS proposals involve transporting the CO_2 to a sequestration site by pipeline, though it can also be transported by tanker. The United States already has more than 2,500 km of CO_2 pipelines in the western part of the country (which are used in EOR operations), so this is not an untested technology.[40] Pipeline costs increase in a linear fashion as distance increases, so coal plants located near sequestration sites will have a significant cost benefit over those that are not.[41]

CO_2 SEQUESTRATION

There are four major carbon sequestration projects currently under way: the Sleipner project in the North Sea, the In Salah project in Algeria, the Weyburn project in southern Saskatchewan (all three of which have been operating for several years),[42] and the recently begun Snohvit project off the coast of Norway.[43] The Weyburn project, which has the added goal of EOR, buys its CO_2 from the Dakota Gasification Company plant mentioned above and is the only project using CO_2 obtained from coal. (The other projects all receive their CO_2 as a by-product of natural gas production.) The annual quantity of CO_2 sequestered at these projects ranges from 0.75 million metric tons (Snohvit) to 1.5 million metric tons (Weyburn).[44]

Smaller sequestration projects are also under way around the world and other large projects are pending.[45] In the United States, seven regional partnerships have been formed to pursue large-scale sequestration projects—six of which were recently awarded grants by the DOE.[46] Two of these regional projects, in the Southeast and North Dakota, will receive CO_2 from post-combustion capture at existing coal plants. The Plains CO_2 Reduction Partnership, based at the University of North Dakota, may receive its CO_2 from the Antelope Valley lignite plant mentioned above, but final plans have not been announced.

If carbon sequestration is to play a meaningful role in reducing global warming pollution, it will have to overcome a number of challenges: scale, slow leakage (which would contribute to warming), fast leakage (which would pose a threat to public safety), contamination of groundwater supplies, seismic events, cost, and public acceptance. Moreover, not all areas of the country have suitable geologic formations; plants built in areas without local sequestration options will face additional transportation costs.

Scale. While none of the existing or proposed projects sequester more than 1.5 million tons of CO_2 yearly, it should be noted that a single 600 MW supercritical coal plant emits about 4 million metric tons annually. The Massachusetts Institute of Technology (MIT) estimates that if 60 percent of the CO_2 currently generated by U.S. coal plants were captured and compressed for sequestration, its volume would equal the total U.S. oil consumption of 20 million barrels per day.[47] Therefore, in order for CCS to make a major contribution to long-term emissions reductions (i.e., 3.6 billion metric tons per year by 2050),[48] the world would need 3,600 sites each sequestering 1 million metric tons per year (roughly the size of each of the four major operating projects described above).[49]

Meeting the challenge of scale requires considerable R&D just to identify potential sequestration sites. Studies suggest that the world does have the capacity to store massive quantities of CO_2 underground, especially in saline formations,[50] but identifying specific sites that can be counted on to store the CO_2 indefinitely represents a massive undertaking.

Leakage and migration. The IPCC concludes that the fraction of CO_2 that will be retained in an appropriately selected and managed sequestration site is "very likely" to exceed 99 percent over 100 years and "likely" to exceed 99 percent over 1,000 years. Various trapping mechanisms in a well-selected site, such as an impermeable caprock that prevents the CO_2 from rising, would gradually immobilize the CO_2 and could retain it for millions of years.[51] Injection into oil and gas fields, saline aquifers at depths greater than 800 meters, and seismically stable areas are considered most appropriate. However, it may not always be easy to ensure that a caprock is truly impermeable, particularly in areas of prior oil and gas production or exploration where wells have already pierced the caprock.

Slow leakage from sequestration sites would of course contribute to global warming. Sudden leakage of large amounts of CO_2 from a sequestration site (or pipeline) would pose a serious danger to the local population, as CO_2 is heavier than air and can accumulate in fatal concentrations. The IPCC concludes that these local dangers are comparable to the risks of current activities such as natural gas storage.[52]

Another potential risk posed by sequestered CO_2 is that it could migrate from a saline aquifer or other formation into which it is injected into a freshwater aquifer, contaminating what would otherwise be a useful drinking water supply. This would be particularly dangerous if the CO_2 were accompanied by other contaminants from coal plant emissions, or if it were to dissolve and transport toxic compounds that already existed underground.

Recent research has found that CO_2 injected into a saline aquifer formed from sandstone acidifies the water considerably, causing certain minerals in the sandstone to dissolve. Because some of these minerals typically seal pores and fractures in the overlying rock formations, their dissolution could allow the CO_2 and acidified saline to migrate into potable water supplies. The acidity could also dissolve cement seals used to close abandoned oil and gas wells, creating other possible migration routes.[53]

Every sequestration project therefore requires long-term measurement, monitoring, and verification of how much CO_2 has been injected and where it has gone. Seismic surveys conducted at sequestration sites can delineate the boundary of the CO_2 plume and can detect some indicators of leakage.[54] Whatever systems are put in place will have to be capable of tracking CO_2 over a very large area—the plume from a project injecting 1 million tons of CO_2 every year for 20 years into a saline aquifer would spread horizontally for 15 square miles or more,[55] but the average coal plant produces 4 million tons of CO_2 per year.

Seismic events. There is some risk that pumping such large volumes of CO_2 underground could trigger damaging earthquakes, though MIT states that the risk is "extremely low."[56] CO_2 that is already being pumped underground for the purpose of EOR has not caused any seismic events. Nevertheless, given the massive scale of sequestration being contemplated, the risk of CO_2-induced earthquakes must be more fully studied.

The environmental and safety risks associated with CCS can likely be made comparable to other major industrial undertakings. But it will require a large investment to identify the most appropriate sites, an ongoing commitment to monitoring those sites for the very long term, and a regulatory structure to establish and enforce appropriate performance and safety standards.

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APPENDIX B

Coal Fuel Cycle Issues

Fuel cycle costs related to coal use fall into three general categories: mining, transportation, and combustion.

- Mining costs vary by region and mining method, and include occupational accidents, "black lung" disease, loss of wildlife habitat caused by surface mining, subsidence caused by underground mining, blasting damage to area structures, air pollution generated by blasting and mining equipment, increased regional flooding due to runoff from mined areas, acid drainage, pollution caused by mine waste, and emissions of methane (a potent heat-trapping gas).
- Transportation costs can be divided into three subcategories: costs related to the long trains and barges that carry most coal to its destination (including fuel consumption, accidents, and particulate emissions); costs related to coal slurry pipelines (including water use and contamination); and costs related to coal-hauling trucks (including accidents, particulate emissions, and road damage).
- Combustion costs include major air-quality problems caused by the emission of air pollutants other than CO_2 from coal-fired power plants: sulfur dioxide, nitrogen oxides, particulate matter, and mercury, among others. Together they contribute to a long list of health- and environment-related costs, including illness and premature death due to heart and lung disease; neurological damage; damage to forests, lakes, and streams caused by acid rain; ecosystem and crop damage caused by ground-level ozone; and impaired visibility. Coal-fired power plants also place significant demands on groundwater and surface water supplies, affecting both water quantity and quality, and create large amounts of solid and liquid wastes that can leach heavy metals and other toxic substances into ground and surface waters.

This appendix discusses four aspects of the coal fuel cycle with particularly serious risks that must be addressed—especially if the United States continues to expand and extend coal's role in the energy sector by subsidizing the coal industry: mountaintop removal mining, mine waste impoundments, mine safety, and non-CO_2 air pollutants from coal plants.

MOUNTAINTOP REMOVAL MINING

While coal mining has long caused environmental damage, the most destructive mining method by far is a relatively new one called mountaintop removal, currently practiced in southern West Virginia and eastern Kentucky. This method permanently destroys a mountain and its adjacent valleys and streams in exchange for a few short years of coal production.

Once all of the trees have been stripped from the mountaintop, its top several hundred feet are blasted away with explosives, often damaging the foundations and wells of local residents and occasionally causing deadly accidents. The rock debris is dumped into an adjacent valley, burying the streams and destroying everything that once grew there. The practice leaves behind a flattened area with soils so poor they can only support grasses. Grasslands are not native to this wooded area, so the resulting landscape represents a profoundly changed environment.[1]

Mountaintop removal has already (and permanently) transformed parts of Appalachia. According to a 2002 federal study, the amount of deforestation related to the mining of the past 10 years and the next 10 years will amount to about 1.4 million acres, or about 11.5 percent of the area being studied.[2] It has been projected that the loss and fragmentation of so much ecologically valuable forest could put some 244 species at risk.[3] More than 700 miles of some of the most biologically diverse streams in the country have been buried, and another 1,200 miles have been directly affected by sediment. It is predicted that in the next 10 years another 1,000 miles of streams will be directly affected, along with many more miles downstream indirectly affected by a loss of nutrients and increased pollution.[4]

Another legacy of mountaintop removal is increased flooding. Runoff from the disturbed areas, which are lacking in vegetation and even soil, is estimated by one study to be three to five times higher than runoff from undisturbed areas, causing a much greater risk of local flooding.[5] In fact, a jury recently found that some of the 2001 flooding in Appalachia was caused by mountaintop removal.[6]

Surface mining in Appalachia accounts for only 13 percent of the U.S. coal supply. Mountaintop removal as a percent of total surface mining is hard to estimate, but probably represents less than half the total, thereby accounting for less than 7 percent of the nation's coal. If the practice were banned, it would not take long to replace this level of production elsewhere. While other types of mining operations also present environmental problems, the damage is far less dramatic than that caused by mountaintop removal.

MINE WASTE IMPOUNDMENTS

Highly mechanized mining methods, including mountaintop removal and "longwall" underground mining, pick up a great deal of non-coal material along with the coal. In some cases, 50 percent of what is mined is disposed of as waste.[7] The coal is separated from this waste material with water and solvents that produce a huge amount of wet coal "slurry" containing dirt, stone, fine coal, and a variety of toxic compounds from both the coal and the solvents.

This waste is disposed of in impoundments (or so-called slurry ponds) typically constructed by blocking off part of a valley with a dam formed from waste rock. These dams are 10 times more likely to fail than regular earthen dams. Hundreds of millions of gallons of mine waste go into such "ponds," of which there are more than 700 in Appalachia already.[8]

The danger posed by mine waste impoundments is more than just hypothetical. A 1972 impoundment dam failure in Buffalo Creek, WV, resulted in a flood of slurry that killed 125 people and left 4,000 homeless.[9] Another West Virginia impoundment is located about one mile uphill from an elementary school.[10]

Mine waste could also break through the bottom of an impoundment. A 2000 breach in Inez, KY, allowed 300 million gallons of waste (roughly 30 times the volume of oil released by the Exxon Valdez) to spill into abandoned underground mine shafts and then into the Big Sandy River, killing 1.6 million fish and contaminating the water supply of 27,000 people in downstream communities. Fortunately, no people were killed. Today, there are 240 impoundments similarly built above abandoned mines.[11]

MINE SAFETY

Though mining deaths have declined over the years, from 260 in 1970[12] to 33 in 2007 (partly due to job losses),[13] coal mining remains a dangerous occupation, with fatality rates at least five times higher than the average for all private industries.[14] Officials with the United Mine Workers have speculated that some of the recent high-profile mine accidents may be related to the fact that rising coal prices have encouraged the reopening of marginally profitable mines with poor safety records. Another factor may be a change in enforcement philosophy at the Mine Safety and Health Administration, which has reportedly taken a less aggressive approach under the George W. Bush administration, focusing more on training than enforcement.[15]

Deaths caused by black lung disease have also been declining since the early 1980s, but between 1999 and 2004 black lung disease still caused an average of 355 deaths yearly.[16] Some newer underground mining technologies that raise coal dust levels may increase a miner's risk of contracting this disease.[17]

NON-CO_2 EMISSIONS

A remarkable number of our nation's most stubborn and dangerous air quality problems can be traced to coal. Fine particulate pollution from U.S. power plants (most of them coal-fired) contributes to heart and lung diseases, including lung cancer, that shave an average of 14 years off the lives of nearly 24,000 people annually. Power plant pollution also causes 38,200 non-fatal heart attacks yearly, tens of thousands of emergency room visits, and hundreds of thousands of asthma attacks, cardiac problems, and respiratory problems.[18]

Fine particulate matter is in large part generated by the sulfur dioxide and nitrogen oxides emitted from coal plants. These pollutants also create acid rain that contributes to ongoing damage to our forests, streams, and lakes. In addition, nitrogen oxides contribute to the formation of ground-level ozone, or smog, which is associated with decreased lung function, asthma attacks, susceptibility to respiratory infections, and increased hospital admissions, as well as damage to crops, forests, and ecosystems.[19]

Coal plants are also the largest U.S. source of man-made mercury emissions.[20] Mercury is a potent neurotoxin that accumulates in the tissues of fish and people who eat fish. It is a particularly serious threat to fetuses and young children, in whom it may cause developmental and neurological damage.

Millions of U.S. women of reproductive age have mercury levels in their blood that could pose a risk to a developing fetus.[21]

To a large extent, these health and environmental problems are caused by older coal plants that lack pollution controls. New regulations under the Clean Air Act, along with a recent court decision requiring tighter federal regulation of mercury emissions, will force many operators of such plants to install pollution controls, pay a higher price for pollution allowances, or close their older plants altogether. When making this choice, plant operators will need to bear in mind that federal limits on CO_2 emissions are in all likelihood inevitable—a consideration that may drive the closure of older coal plants that would otherwise be retrofitted with sulfur dioxide, nitrogen oxide, particulate, and mercury controls. Some of these older plants could be replaced with new, more efficient ones that capture their CO_2 and greatly reduce other pollutants in the process.

ENDNOTES TO APPENDIX B

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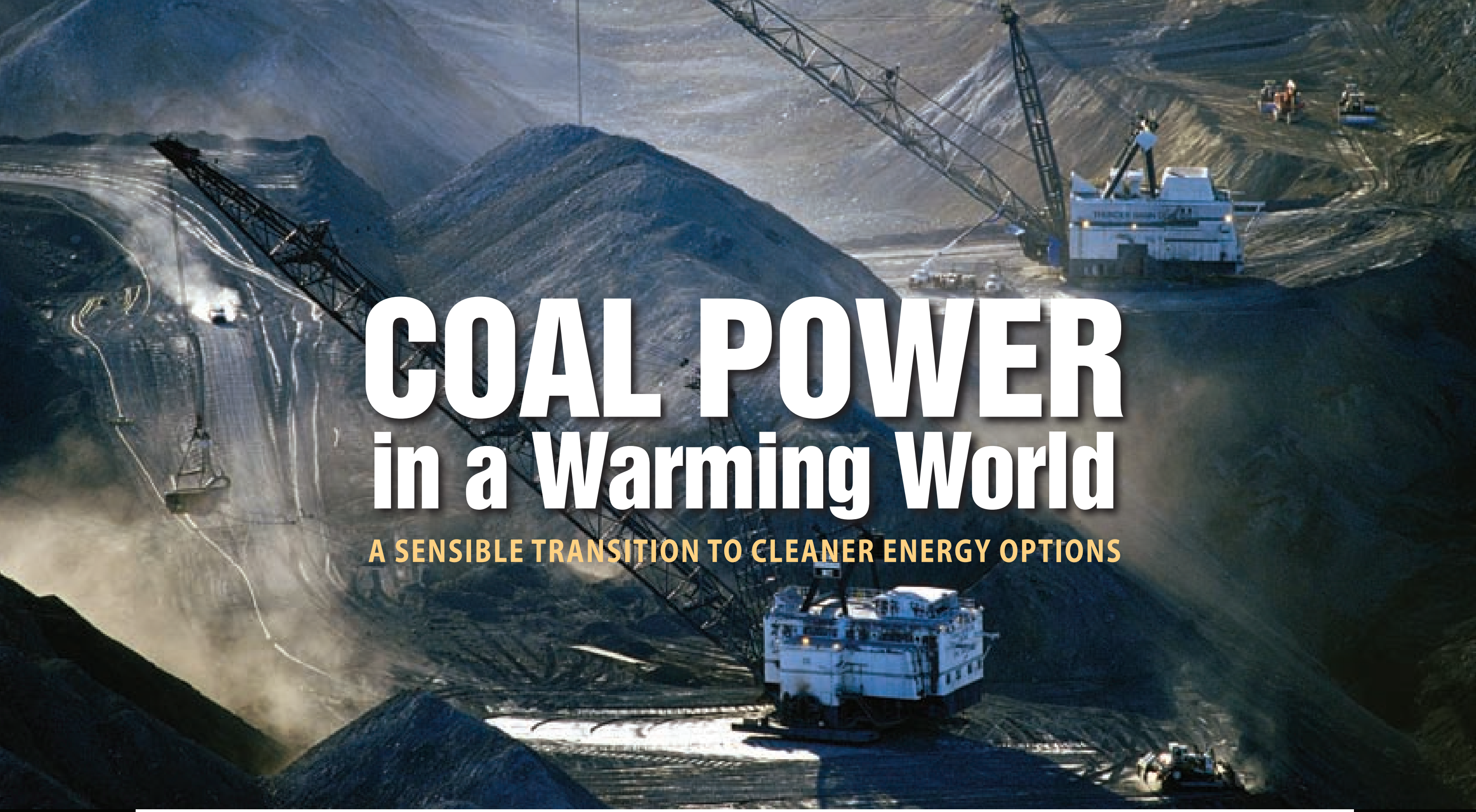

COAL POWER in a Warming World

A SENSIBLE TRANSITION TO CLEANER ENERGY OPTIONS

Coal-fired power plants are the United States' largest source of global warming pollution, yet our nation is poised to greatly increase this pollution by building many new coal plants. Only a few of the proposed plants would use emerging pollution control technology called carbon capture and storage (CCS); the rest could lock the country into decades of higher carbon emissions and prevent us from making the cuts needed to avoid the worst effects of global warming.

In this report, the Union of Concerned Scientists discusses the dangers of current U.S. coal policies and sets forth the changes vital to building a safer energy future. We call for accelerated research into CCS, including 5 to 10 demonstration projects, as well as an immediate end to the construction of new coal plants not using such technology.

Additional policy changes should include: eliminating subsidies and other support for coal-to-liquid facilities; ensuring that any coal-to-gas technologies actually reduce global warming pollution; accelerating investment in renewable energy and energy efficiency; reducing the environmental damage caused by coal mining and use; establishing a cap-and-trade system to reduce pollution from existing plants; and sharing the results of CCS demonstration projects (and other low-carbon technologies) with developing nations.

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