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Report to the Chairman of the Select Committee on Energy Independence and Global Warming, House of Representatives

September 2008

CLIMATE CHANGE

Federal Actions Will Greatly Affect the Viability of Carbon Capture and Storage As a Key Mitigation Option

GAO-08-1080

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Highlights

Highlights of GAO-08-1080, a report to the Chairman of the Select Committee on Energy Independence and Global Warming, House of Representatives

Why GAO Did This Study

Key scientific assessments have underscored the urgency of reducing emissions of carbon dioxide (CO_2) to address climate change. Many have cited carbon capture and storage (CCS) as an essential technology because it has the potential to greatly reduce CO_2 emissions from power plants while allowing for projected increases in electricity demand. CCS involves capturing CO_2 from a power plant's emissions, transporting it to an underground storage location, and then injecting it into a geologic formation for long-term storage.

As requested, GAO examined (1) key economic, legal, regulatory, and technological barriers impeding commercial-scale deployment of CCS technology and (2) actions the Department of Energy (DOE), Environmental Protection Agency (EPA), and other agencies are taking to overcome barriers to commercial-scale deployment of CCS technology. Among other things, GAO examined key studies and contacted officials from pertinent agencies, companies, and environmental groups, as well as research and other organizations.

What GAO Recommends

Among GAO's recommendations are that (1) DOE continue to place greater emphasis on CO_2 capture at existing power plants and (2) EPA examine how its statutory authorities can be used to address potential CCS barriers. DOE neither explicitly agreed nor disagreed with the first recommendation. EPA expressed general agreement with the second recommendation.

To view the full product, including the scope and methodology, click on GAO-08-1080. For more information, contact John Stephenson at (202) 512-3841 or stephensonj@gao.gov.

What GAO Found

Nationally-recognized studies and GAO's contacts with a diverse group of industry representatives, nongovernmental organizations, and academic researchers show that key barriers to CCS deployment include (1) underdeveloped and costly CO_2 capture technology and (2) regulatory and legal uncertainties over CO_2 capture, injection, and storage. Key technological barriers include a lack of experience in capturing significant amounts of CO_2 from commercial-scale power plants and the significant cost of retrofitting existing plants that are the single largest source of CO_2 emissions in the United States. Regulatory and legal uncertainties include questions about liability concerning CO_2 leakage and ownership of CO_2 once injected. According to the National Academy of Sciences and other knowledgeable authorities, another barrier is the absence of a national strategy to control CO_2 emissions (emissions trading plan, CO_2 emissions tax, or other mandatory control of CO_2 emissions), without which the electric utility industry has little incentive to capture and store its CO_2 emissions. Moreover, according to key agency officials, the absence of a national strategy to control CO_2 emissions has also deterred their agencies from resolving other important practical issues, such as how sequestered CO_2 will be transported from power plants to appropriate storage locations and how stored CO_2 would be treated in a future CO_2 emissions trading plan.

Federal agencies have begun to address some CCS barriers but have yet to comprehensively address the full range of issues that would require resolution for large-scale CCS deployment:

- *DOE's* research strategy has, until recently, devoted relatively few resources to lowering the cost of CO_2 capture from existing coal-fired power plants, focusing instead on innovative technologies applicable to new plants. In recent years, however, the agency has begun to place greater emphasis on CCS technologies applicable to existing facilities.

- *EPA* issued in July 2008 a proposed rule to guide the permitting of large volume, or commercial-scale, CO_2 injections. It addressed at least some of the key issues under the Safe Drinking Water Act but left other issues related to EPA's implementation of its air, hazardous waste and substance statutes unresolved.

- *Other agencies*, such as Interior and Transportation, have jurisdiction over a number of interdisciplinary issues that could delay CCS deployment if unaddressed, but which have thus far received little attention. These include, among others, a legal and regulatory regime for a national CO_2 pipeline infrastructure and a plan for addressing CO_2 emissions reductions from CCS in a future emissions trading plan. In addition, unless the effects of CCS deployment are clearly explained, public opposition could delay future CCS projects.

Contents

Figures

Abbreviations

AoR	Area of Review
BLM	Bureau of Land Management
CCS	carbon capture and storage
CCTP	Climate Change Technology Program
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CO_2	carbon dioxide
DOE	Department of Energy
EPA	Environmental Protection Agency
ETS	Emissions Trading Scheme
EU	European Union
FERC	Federal Energy Regulatory Commission
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
MIT	Massachusetts Institute of Technology
NSR	New Source Review
PHMSA	Pipeline and Hazardous Materials Safety Administration
RCRA	Resource Conservation and Recovery Act
SDWA	Safe Drinking Water Act
SO_2	sulfur dioxide
STB	Surface Transportation Board
UIC	Underground Injection Control
UNFCCC	United Nations Framework Convention on Climate Change
USGS	U.S. Geological Survey

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Accountability * Integrity * Reliability

United States Government Accountability Office
Washington, DC 20548

September 30, 2008

The Honorable Edward Markey
Chairman
Select Committee on Energy Independence
and Global Warming
House of Representatives

Dear Mr. Chairman:

Key scientific assessments have underscored the urgency of reducing emissions of carbon dioxide (CO_2), the most significant greenhouse gas, to help mitigate the negative effects of climate change. Given the United States' heavy reliance on coal-burning power plants that emit significant quantities of CO_2, many have cited carbon capture and storage (CCS) as an essential technology because it can greatly reduce CO_2 emissions from these facilities, while allowing for projected increases in electric power demand.[1] CCS is a process of separating CO_2 from other gases produced in fuel combustion and other industrial processes, transporting the CO_2 via pipeline to an underground storage location, and injecting and storing it long-term in underground geologic formations.

While other climate mitigation options exist—such as energy efficiency improvements, a switch to less carbon-intensive fuels, nuclear power, and renewable energy sources—CCS is considered by many to be a crucial component of any U.S. approach or strategy for addressing the climate change problem, particularly given the United States' current reliance on coal for almost half of its electricity production. Moreover, there is a large potential role for CCS in rapidly developing countries, such as China and India, which will be relying increasingly on coal to meet their energy needs. In fact, as of 2007, Chinese CO_2 emissions likely exceeded those of the United States, according to the International Energy Agency (IEA).[2]

[1]CCS can also be used to reduce the CO_2 emissions from industrial production of hydrogen, chemicals, substitute natural gas, and transportation fuels.

[2]The International Energy Agency (IEA) is an intergovernmental organization founded in 1974 that acts as energy policy advisor to 27 member countries. The IEA's current work focuses on climate change policies, market reform, and energy technology collaboration and outreach.

The IEA projects continued growth in CO_2 emissions from China and other developing economies.

At present, there are few commercial-scale CCS projects in operation. While recent assessments by the IEA and the Intergovernmental Panel on Climate Change (IPCC) have indicated that CCS could be a key contributor to controlling greenhouse gas emissions worldwide,[3] a number of barriers may preclude its widespread use. Therefore, many organizations, including the IEA, emphasize that it will be critical to overcome these barriers and demonstrate the feasibility of this technology. In this context, this report examines (1) the key economic, legal, regulatory, and technological barriers impeding commercial-scale deployment of CCS technology and (2) the actions federal agencies are taking to overcome barriers to or facilitate the commercial-scale deployment of CCS technology.

To examine barriers to CCS, we conducted a literature review and synthesized CCS-related information contained in a number of key reports, including those by the IPCC, the National Academy of Sciences, and by various federal agencies. We also contacted a nonprobability sample of electric power companies, major oil and gas companies, CO_2 pipeline owners, environmental organizations, and researchers at think tanks and universities to determine their perspectives on key barriers to CCS deployment at commercial scale. We selected major U.S. energy producing companies, as well as organizations and researchers that participate actively in ongoing dialogues on CCS. We also selected a number of smaller companies and organizations to ensure that we obtained a broader range of perspectives on key issues.[4] We used a semistructured interview guide to (1) obtain information from individual stakeholders on key barriers to CCS deployment at commercial scale and (2) facilitate an aggregate analysis of stakeholder perspectives on key barriers to CCS.

[3]The Intergovernmental Panel on Climate Change (IPCC) is a scientific body set up by the World Meteorological Organization and by the United Nations Environment Programme. The IPCC was established to provide decision makers with an objective source of information about climate change.

[4]Results from nonprobability samples cannot be used to make inferences about a population. This is because, in a nonprobability sample, some elements of the population being studied have no chance or an unknown chance of being selected as part of the sample.

To examine federal actions to address CCS barriers, we obtained and analyzed information from the Environmental Protection Agency (EPA), the Department of Energy (DOE), and other federal agencies regarding their CCS-related activities. We collected 12 years of budget information from DOE's Coal Program and followed up on recommendations contained in two recent EPA and DOE advisory committee reports. We also attended two EPA Underground Injection Control program workshops and followed up with EPA officials on stakeholder concerns expressed at these meetings. Using the methodology described for our first objective, we obtained the perspectives of industry stakeholders, environmental organizations, and researchers at think tanks and universities on federal agency actions to overcome barriers to, or to facilitate deployment of, commercial-scale CCS in the United States. We conducted this performance audit from October 2007 to September 2008 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Results in Brief

Nationally-recognized studies and our contacts with a diverse group of industry representatives, nongovernmental organizations, and academic researchers show that key barriers to CCS deployment include (1) underdeveloped and costly CO_2 capture technology and (2) regulatory and legal uncertainties over CO_2 capture, injection, and storage. Among the key technological barriers are a lack of experience in capturing significant amounts of CO_2 from power plants and the significant cost of capturing CO_2, particularly from existing coal-fired power plants, which are the single largest source of CO_2 emissions in the United States. Compounding these technological issues are regulatory and legal uncertainties, including uncertainty regarding liability for CO_2 leakage and ownership of CO_2 once injected. According to the IPCC, the National Academy of Sciences, and other knowledgeable authorities, another barrier is the absence of a national strategy to control CO_2 emissions (emissions trading plan, CO_2 emissions tax, or other mandatory control of CO_2 emissions), without which the electric utility industry has little incentive to capture and store its CO_2 emissions. Moreover, according to key agency officials, the absence of a national strategy has also deterred their agencies from addressing other important practical issues, such as resolving how stored CO_2 would be treated in a future CO_2 emissions trading plan.

Federal agencies have begun to address some CCS barriers but have yet to comprehensively address the full range of issues that would require resolution for commercial-scale CCS deployment:

- *Key technological barriers*. DOE has achieved limited results in lowering the cost of CO_2 capture from existing coal-fired power plants. A major reason is that the agency has focused on "Integrated Gasification Combined Cycle" (IGCC) technology, a promising technology for new coal-fired power plants, but one that is less useful when applied to existing coal power plants. The agency has only recently begun to shift toward an approach that also emphasizes CCS technologies applicable to existing power plants.

- *Key legal and regulatory barriers*. The EPA issued a proposed rule in July 2008 concerning underground injection of CO_2 for geologic sequestration. Because of the large injection volumes associated with geologic sequestration, this proposed rule would apply to commercial-scale injections. The proposed rule was issued under the agency's Safe Drinking Water Act (SDWA) authority. However, some issues that fall outside of this authority are still unresolved. These include whether and how the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA) apply to injected CO_2. Also unresolved are issues concerning how the Clean Air Act's requirements will apply to existing power plants that install CCS.

- *Other considerations*. Even if the DOE- and EPA-related issues are resolved, there are a number of issues, many of which cross the jurisdictions of multiple agencies, that could delay CCS deployment if not addressed in a timely fashion. These include whether the federal government could be held liable if CO_2 stored below public lands leaked onto adjoining nonfederal property. In addition, a number of federal agencies (such as the Federal Energy Regulatory Commission, the Surface Transportation Board, Department of Transportation, DOE, and EPA) will need to work together to examine how CO_2 pipeline infrastructure might be regulated to accommodate commercial-scale CCS. Others will need to devise a plan for how CO_2 emissions reductions from CCS will be treated in a future emissions trading scheme.

We are making a number of recommendations to agencies with major CCS-related responsibilities to address key barriers to CCS deployment. To better ensure that DOE's research and development efforts address CCS at both new coal-fired power plants and existing plants, we are recommending that DOE continue its recent practice of placing a greater

emphasis on technologies that can reduce CO_2 emissions from existing coal-fired power plants. In commenting on a draft of this report, DOE's September 9, 2008, letter neither explicitly agreed nor disagreed with this recommendation but included a number of comments that recognized a need for increased funding for CO_2 emissions control technologies for existing coal-fired power plants.

To enhance EPA's ability to address barriers that may be affecting CCS deployment, we are recommending that EPA more comprehensively examine barriers to CCS development beyond those relevant to the SDWA, by addressing issues under RCRA, CERCLA, and other statutes within the agency's jurisdiction. EPA's September 12, 2008, letter responded that providing regulatory certainty on issues related to geological storage of CO_2 was a high priority for the agency and agreed with the intent of the recommendation—to provide clarity on how statutes within the agency's jurisdiction may apply. The agency noted that it had made an initial effort to identify and discuss these issues in the preamble of its July 2008 proposed rulemaking and had requested comments on many of the SDWA topics—including some of those identified in our report. It said it expected further progress on the SDWA topics after receiving input from stakeholders during the comment period (which extends through November 24, 2008).

Finally, we are recommending that an interagency task force (or similar mechanism) be established to develop a comprehensive strategy that guides cognizant federal agencies in resolving remaining issues that, if not addressed proactively, could impede commercial-scale CCS deployment. DOE maintained that a coordinating body—the DOE-led Climate Change Technology Program (CCTP)—already addresses these kinds of issues. However, the CCTP's scope focuses on technology; it does not address legal and institutional issues, such as the resolution of CO_2 pipeline regulation and infrastructure, among others. In addition, officials from cognizant offices within the Departments of the Interior and Transportation told us they have not yet been invited to participate in CCTP discussions. Moreover, we continue to believe that a more centralized task force with a broader mission, perhaps authorized by the Executive Office of the President, would be a preferable alternative.

DOE's and EPA's comments are addressed at the end of this letter and reproduced in appendixes II and III, respectively (along with our responses to each of their main points). The agencies also provided technical comments separately, which have been incorporated in our final report, as appropriate. In addition, we sought and received clarification and verification on specific issues from the Department of the Interior's

Bureau of Land Management and U.S. Geological Survey; the Department of Transportation's Pipeline and Hazardous Materials Safety Administration; the Federal Energy Regulatory Commission; and the Surface Transportation Board, and have incorporated their input in finalizing the report.

Background

There is growing concern about climate change and the impact it will have on people and the ecosystems on which they depend. According to the National Academy of Sciences, global temperatures have already risen 1.4 degrees Fahrenheit since the start of the 20th century—with much of this warming occurring in the last 30 years alone—and temperatures will likely rise at least another 2 degrees Fahrenheit, and potentially more than 11 degrees, over the next 100 years. This warming will cause significant changes in sea level, ecosystems, and ice cover, among other impacts. In the Arctic region, temperatures have increased almost twice as much as the global average, and the landscape is changing rapidly. Most scientists agree that the warming in recent decades has been caused primarily by human activities that have increased the amount of greenhouse gases in the atmosphere. Greenhouse gases, such as CO_2, have increased markedly since the Industrial Revolution, mostly from the burning of fossil fuels for energy, industrial processes, and transportation. According to the National Academy of Sciences, CO_2 levels are at their highest in at least 650,000 years and continue to rise.

In 1992, the first major multilateral treaty on global warming, the United Nations Framework Convention on Climate Change (UNFCCC), was finalized. One hundred ninety-two countries, including the United States, have ratified this treaty and agreed to its objective to "achieve…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The UNFCCC required signatory states to publish greenhouse gas emission levels; formulate a national response to climate change; and develop and distribute technologies to control, reduce, or prevent greenhouse gas emissions. However, its mitigation provisions focused on voluntary efforts by signatory states. Under the Kyoto Protocol to the UNFCCC, 37 industrialized countries have agreed to reduce or limit their greenhouse gas emissions by an average of 5 percent below 1990 levels between 2008 and 2012. Also, in 2005, the European Union (EU) began implementing its Emissions Trading Scheme (ETS), a program that limits CO_2 emissions in each member state and is intended to help states achieve their commitments under the Kyoto Protocol. Many countries with significant greenhouse gas emissions, including the United States, China, and India, have not committed to

binding limits on emissions through the Kyoto Protocol or other mechanisms as of the date of this report. Despite the UNFCCC's ratification, global annual fossil fuel-related CO_2 emissions increased from an average of approximately 23.5 billion metric tons of CO_2 per year in the 1990's to approximately 26.4 billion metric tons of CO_2 per year from 2000 to 2005.[5]

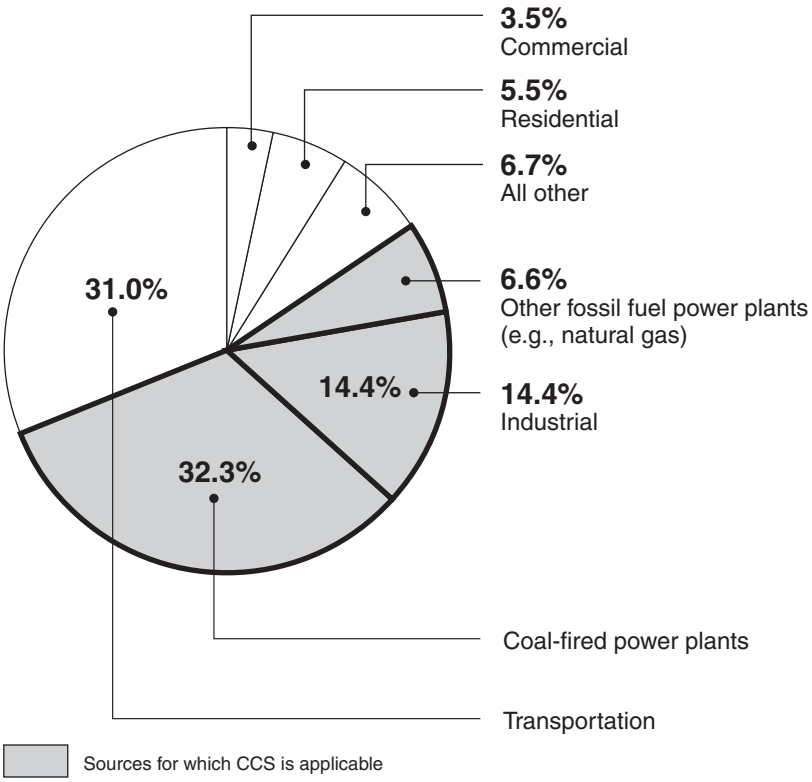
A complicating factor in addressing this increase in temperature is the heavy reliance by the United States and other countries on coal-fired power plants for electric power generation. Coal accounts for about half of electricity generation in the United States. Moreover, according to the IEA, coal is used to produce more than half of several other nations' electricity, including South Africa, Poland, China, Australia, and India.

Coal-fired power plants are one of the largest sources of CO_2 emissions. In the United States, coal-fired power plants account for approximately one-third of total CO_2 emissions. Figure 1 shows total U.S. CO_2 emissions, what portions are from each sector of the economy, and sources where CCS could more readily be used.[6]

[5]The IPCC notes that these emissions include those from the production, distribution, and consumption of fossil fuels and as a by-product from cement production. The data from 2004 and 2005 are interim estimates.

[6]CCS is not considered suitable for reducing emissions from the transportation, residential, and commercial sectors because sources in these sectors tend to emit small quantities of CO_2.

Figure 1: Contribution of Coal-Fired Power Plants and Other Sources to Total U.S. CO_2 Emissions



Source: GAO analysis of data from the Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006* (April 2008).

To complicate matters further, increased energy demands are projected for the future, both in the United States and worldwide. The IEA projects that if governments around the world proceed with current policies, the world's energy needs would be over 50 percent higher in 2030 than today.[7] For the United States, an assessment by DOE's Energy Information Administration indicates that electricity sales will increase 29 percent by 2030, if current policies continue. Moreover, the IEA anticipates that the two largest developing countries—China and India—will drive increased

[7]The IEA's 2007 *World Energy Outlook* also assesses two alternative scenarios. These include a scenario in which world demand for energy and coal generally increases less than otherwise expected due to changes in government policies that address climate change concerns and a scenario in which world demand increases more than otherwise expected due to higher rates of economic growth in China and India.

demand for coal to meet growing electricity demand. The IEA notes that China and India's heavy reliance on coal has already contributed significantly to recent increases in global CO_2 emissions, with China likely overtaking the United States as the largest CO_2 emitter in 2007.

In order to prevent this dramatic increase in coal-based energy production from emitting significant amounts of CO_2 to the atmosphere, many are suggesting CCS as a unique tool that allows for continued coal use, while mitigating its associated effect on the climate. The IEA identifies CCS and other clean coal technologies as one of the most promising routes for mitigating emissions and notes that "CCS could reconcile continued coal burning with the need to cut emissions in the longer term." Similarly, the IPCC notes that CCS would help preserve existing energy infrastructure, thereby restraining the cost of emissions reductions. Looking ahead, the IEA projects that CCS could contribute to 21 percent of avoided emissions to stabilize atmospheric CO_2 concentrations at 450 parts per million, a level which is projected to limit the average increase in global temperature to 2.4 degrees Celsius (4.3 degrees Fahrenheit).

The EU is also beginning to highlight the importance of CCS in addressing climate change. In 2008, the EU proposed legislation, known as a proposed directive, on the geological storage of CO_2 that would support the EU policy of limiting global average temperature increases to less than 2 degrees Celsius (3.6 degrees Fahrenheit). Specifically, in 2007, the European Council urged EU member states and the European Commission to develop the necessary technical, economic, and regulatory framework to remove existing legal barriers to CCS so that the technology can be applied to new fossil fuel power plants by 2020, if possible. The following year, the European Commission proposed legislation that would create a legal framework for capture, transport, and geological storage of CO_2 within member states' territories.

CCS is comprised of multiple processes, including CO_2 capture and compression; transport of the CO_2 to a storage location; injection and storage in geologic formations; and monitoring to verify that the CO_2 is staying in place. A successful CCS system must integrate all of them. The first step in CCS is identifying and verifying a suitable location for CO_2 storage. Next, CO_2 would be captured at power plants and other large industrial sources. The goal of CO_2 capture is to produce a concentrated stream of nearly pure CO_2 at high pressure so that it can be transported via pipeline to a storage site. Regardless of the capture approach used, additional energy, often referred to as the energy penalty, is required for capture and compression. Three major approaches to capturing or separating CO_2 from industrial sources have been identified—pre-

combustion capture, post-combustion capture, and oxyfuel combustion capture.[8]

After CO_2 capture and compression, the compressed gas, now in a supercritical state,[9] would likely be transported via pipeline to a storage site, unless a storage site was available at the capture facility. Once at a storage site, the CO_2 would likely be injected well below the surface, at depths of over 800 meters, or about 2,600 feet, into geologic formations thought to be conducive for long-term sequestration (that is, hundreds to thousands of years) from the atmosphere. When injected, the CO_2 is sequestered by a combination of physical and geochemical trapping processes.

Physical trapping occurs because the relatively buoyant CO_2 reaches a layer of rock that inhibits further upward migration. Geochemical trapping occurs when the CO_2 reacts chemically with minerals in the geologic formation that result in the precipitation of solid minerals. Geologic formations, such as depleted oil and gas reservoirs and saline formations, are thought to be particularly favorable for CO_2 storage. These formations tend to have high porosity, or an abundance of pores for CO_2 to fill in, and an impermeable barrier, known as a solid caprock, to keep the buoyant CO_2 from migrating to the surface. Figure 2 depicts CO_2 capture, transport, and storage in geologic formations and highlights the characteristics of caprock and the underlying rock that are favorable for CO_2 storage. DOE and IEA estimates indicate that the United States has appropriate geology that could potentially store over 3 trillion tons of CO_2—enough to store 1,000 years of CO_2 emissions from nearly 1,000 coal-fired power plants.

[8]This report focuses primarily on pre- and post-combustion capture.

[9]When the temperature and pressure of CO_2 are increased, the CO_2 enters a fluid, or supercritical state.

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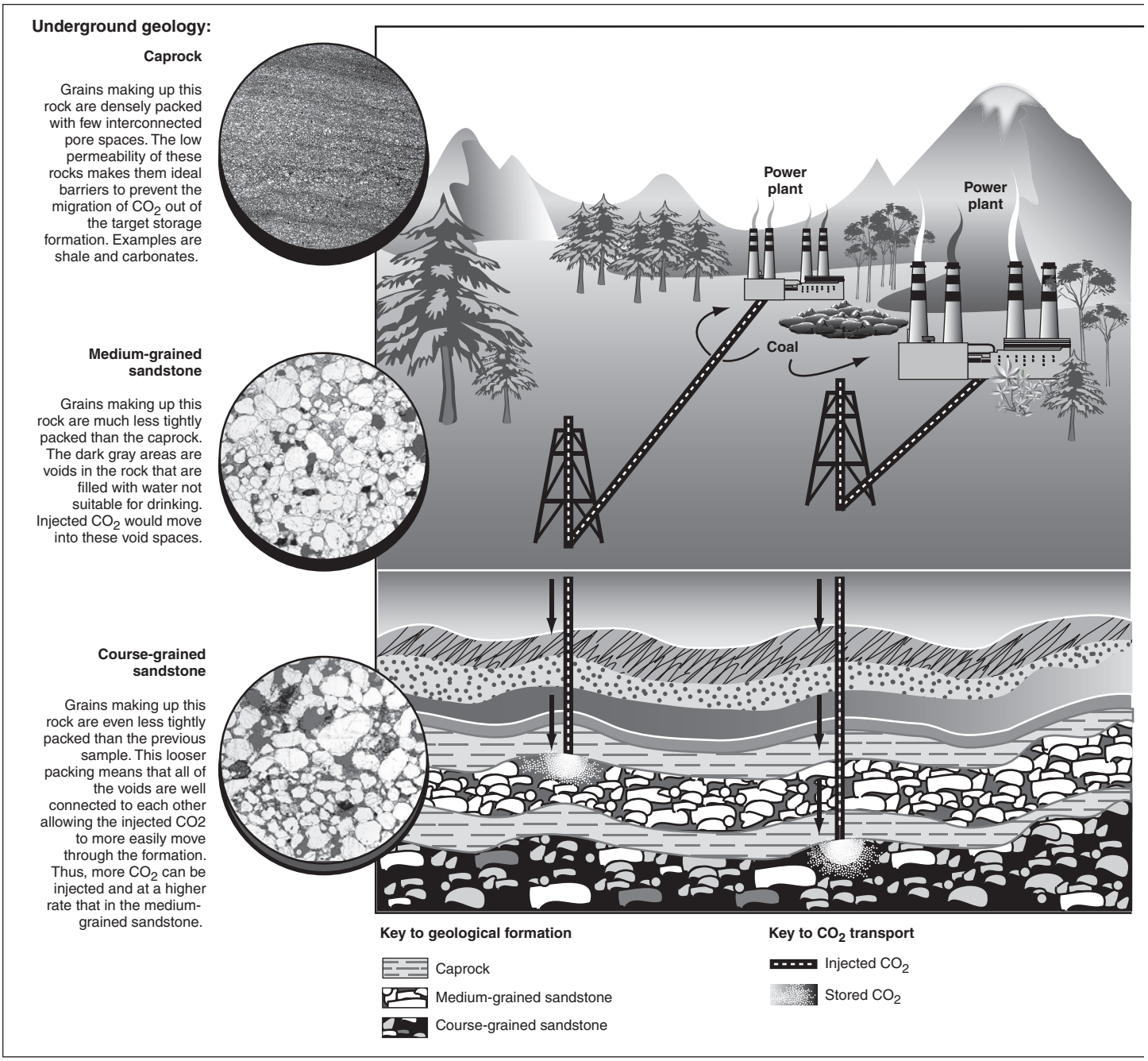
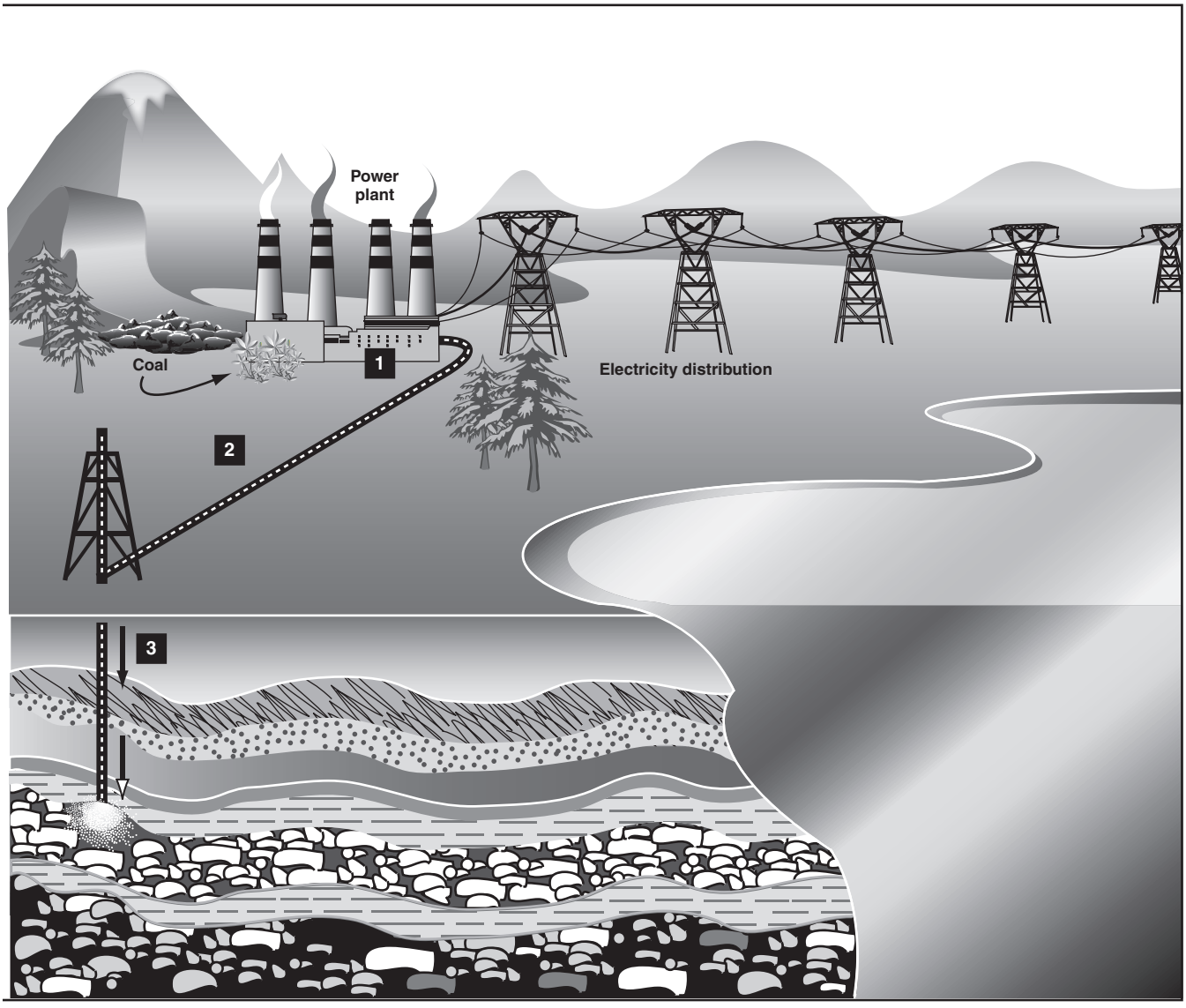
Figure 2: CO_2 Capture, Transport, and Storage in Geologic Formations



Source: GAO analysis of IPCC and Joint Global Change Research Institute, Battelle Pacific Northwest Division data.



Steps in the CO_2 storage process

1. CO_2 capture
2. CO_2 transport
3. CO_2 injection and storage

Multiple federal agencies have programs and other responsibilities that will affect CCS deployment, but the key ones are administered primarily by DOE and EPA:

- DOE is the lead federal agency for supporting the development of clean coal technology, including CCS technology. The agency established the Carbon Sequestration program in 1997 to ascertain the technical viability of CCS. The core research and development in the program involves laboratory and pilot-scale research in areas that include CO_2 capture and storage. The demonstration and deployment element of the program is designed to show the viability of CCS technologies at a scale large enough to overcome real and perceived infrastructure challenges. In order to do so, DOE established a network of seven Regional Carbon Sequestration Partnerships to develop the technology, infrastructure, and regulations necessary to implement CO_2 storage in different regions of the nation. Other DOE programs are also developing technologies related to coal-fueled power generation with CO_2 capture; including (1) the Advanced Integrated Gasification Combined Cycle (IGCC) program to support development of gasification technology to enable CO_2 capture; (2) the restructured FutureGen program to demonstrate IGCC or other advanced coal technology, as well as CO_2 capture; (3) the Innovations for Existing Plants program, which has recently focused more attention on developing technology to facilitate CO_2 capture at existing coal-fired power plants; and (4) the Clean Coal Power Initiative, which is supporting advanced coal-based technologies that capture and sequester CO_2 emissions.

- EPA has authority under the SDWA to regulate underground injections of various substances, including nonhazardous and hazardous wastes into injection wells. Injection wells have a range of uses that traditionally include waste disposal, enhancing oil production, and mining. The SDWA requires EPA to develop minimum federal requirements for injection practices that protect public health by preventing injection wells from endangering underground sources of drinking water. There are five different well types: Class I (injections of hazardous wastes, industrial nonhazardous wastes, municipal wastewater); Class II (injections associated with enhanced oil and gas production); Class III (injections associated with mineral extraction); Class IV (now mostly banned,[10] but formerly, to inject hazardous or radioactive waste above or into an underground source of drinking water); and Class V (wells not included in other classes, including wells used in experimental technologies, such as

[10]An exception is made for groundwater remediation at hazardous waste sites.

pilot CO_2 storage).[11] EPA has given 33 states primacy, or primary enforcement responsibility, to administer the Underground Injection Control (UIC) program, and 7 states have partial responsibility for administering the UIC program.[12]

- The prospect of widespread, nationwide use of CCS would also require the involvement of other agencies with varied responsibilities. The Department of the Interior's Bureau of Land Management, for example, would have broad jurisdiction over CO_2 injected on public lands. Whether the Federal Energy Regulatory Commission or the Surface Transportation Board would have regulatory responsibilities for pipelines transporting captured CO_2 is an issue that needs to be resolved. The CCTP, authorized by the Energy Policy Act of 2005, is tasked with assisting the interagency coordination of climate change technology research, development, demonstration, and deployment. Because the CCTP coordinates interagency discussion of climate change technology issues, it will likely also be involved in any ongoing interagency dialogue on CCS deployment.

Barriers to CCS Deployment Include the High Cost of Current Technologies, Regulatory Uncertainty, and the Lack of a National Strategy to Control CO_2 Emissions

Nationally-recognized studies and our contacts with a diverse group of industry representatives, nongovernmental organizations, and academic researchers show that key barriers to CCS deployment include (1) the high cost of, and lack of experience with, CO_2 capture technologies and (2) regulatory uncertainties concerning CO_2 capture, injection, and storage. Among the technological barriers impeding CCS deployment at coal-burning power plants are the significant cost of retrofitting existing coal-fired power plants and lack of commercial-scale demonstrations. Compounding these technological issues are uncertainties over regulatory and legal issues, including legal uncertainty regarding liability for CO_2 leakage and ownership of CO_2 once injected. According to the IPCC, the National Academy of Sciences, and other knowledgeable authorities, another barrier is the absence of a national strategy to control CO_2 emissions (emissions trading plan, CO_2 emissions tax, or other mandatory control of CO_2 emissions), without which the electric utility industry has little incentive to capture and store its CO_2 emissions. Moreover, according to key agency officials, the absence of a national strategy to control CO_2 emissions has also deterred their agencies from resolving other important

[11]Class V wells are typically shallow wells that place a variety of fluids directly below the land surface.

[12]EPA administers the UIC program in 10 states and for all Indian tribes.

practical issues, such as how stored CO_2 would be treated in a future CO_2 emissions trading plan.

CO_2 Capture Must Overcome Significant Technological Hurdles to be a Cost-Effective Technology for Coal-Fired Power Plants

Capturing CO_2 from large electric power plants, particularly coal-fired power plants, entails a number of technological challenges that affect its cost of deployment, and hence its appeal to industry. Among these challenges are (1) the absence of any commercial-scale demonstration of the technology at a power plant; (2) certain limitations of coal gasification technology for capturing CO_2 emissions at new power plants; and (3) the high cost of retrofitting CCS to existing pulverized coal-fired power plants that will, for the next several decades, account for a significant share of U.S. CO_2 emissions.

CCS Has Yet to Be Demonstrated on a Commercial Scale at a Power Plant

To date, there have been several small-scale tests of CO_2 capture at power plants in the United States and other countries, but these demonstration projects have typically removed CO_2 from only a small fraction of the power plant's overall output. Large-scale demonstrations of CO_2 capture at a power plant have been identified as an important step in improving capture technology, as well as securing industry support for CCS. Hence, the DOE Carbon Sequestration Program's program plan notes that the testing of CCS technologies at a larger scale is important to identify and eliminate technical and economic barriers to commercialization of CCS technology. With the need to accelerate the testing of innovative technologies in mind, two key international organizations—the IEA and the Carbon Sequestration Leadership Forum—recommend that a minimum of 20 full-scale CCS demonstration projects be implemented worldwide by 2020.

In a similar vein, a DOE advisory committee, the National Coal Council, noted that larger-scale demonstrations will be necessary to secure industry support. It noted, in particular, that "deployment will require successful pilot-scale testing and operation at a demonstration scale of 50 to 100 megawatts before companies will have confidence in their cost and performance for large scale systems."[13] Similar opinions were offered by several of the stakeholders we interviewed, who told us they thought it would be helpful for testing to focus more on actual demonstrations, rather than laboratory testing. For example, two electric power company officials told us they thought testing on a larger scale was important

[13]National Coal Council, *Technologies to Reduce or Capture and Store Carbon Dioxide Emissions* (June 2007).

because the reliability of power plants with carbon management has not been adequately considered.

Despite the importance of gaining this kind of experience with CO_2 capture, CO_2 capture has not been demonstrated on a large scale at a power plant in the United States or in any other country. The IPCC's Special Report on CCS observed that "there have been no applications [of carbon capture] at large-scale power plants of several hundred megawatts" and emphasized the significance of this omission by cautioning that large-scale power plants are the major source of current and projected CO_2 emissions.

It should be noted that some progress has been made in testing CCS at other types of industrial facilities. Specifically, four industrial facilities have received attention as major demonstrations of CO_2 capture and storage technology. These facilities presently capture and store anthropogenic CO_2 on a large scale.[14] Three of these projects involve separation of CO_2 from natural gas: the Sleipner and Snohvit projects, located off the coast of Norway, and the In Salah project in Algeria. The fourth project captures CO_2 at a facility in North Dakota, where coal is gasified to make methane. The captured CO_2 is then injected at an oil field in Weyburn, Canada for the purposes of enhanced oil recovery and to permanently store almost all of the injected CO_2.

CO_2 capture has also been demonstrated at other industrial facilities, including plants that purify natural gas and produce chemical products (ammonia, alcohols, and synthetic liquid fuels). For example, one existing industrial application of CO_2 capture is to remove CO_2 from natural gas—a process called natural gas sweetening—to prevent pipeline corrosion and increase the heating value of the gas. However, much of the CO_2 captured at these facilities is currently vented to the atmosphere because there is no requirement or incentive to store it.[15]

[14]The IEA defines large scale as injecting over 0.5 Mt (500,000 metric tons) per year.

[15]The IPCC Special Report on CCS notes that some of the CO_2 captured from natural gas processing and ammonia production facilities is used for enhanced oil recovery, a process which may result in the sequestration of a substantial amount of the CO_2 from the atmosphere.

Nonetheless, according to the IPCC and other knowledgeable authorities, key differences may inhibit the transferability of CO_2 capture at these facilities to coal-fired power plants:

- *Lower CO_2 concentrations at coal-fired power plants*. A study by researchers at the Massachusetts Institute of Technology (MIT) indicated that industrial processes, such as natural gas processing and ammonia production, produce highly concentrated streams of CO_2 as a byproduct, facilitating CO_2 capture.[16] By contrast, CO_2 is relatively diffuse in the exhaust, or flue gas, produced by coal power plants—about 13 to 15 percent by volume—making CO_2 capture substantially more energy intensive.

- *Challenges in adapting the CO_2 removal process to power plants*. The most commonly-used chemical method for removing CO_2 from natural gas may be challenging to adapt to capture at power plants. According to the IPCC Special Report on CCS, CO_2 is most commonly removed from natural gas using chemical solvents. However, DOE officials told us that one such commonly used solvent, monoethanolamine, is not designed to cost-effectively remove the dilute concentrations of CO_2 from the extremely large volumes of flue gas produced by pulverized coal power plants.

The IPCC report noted that applying CO_2 capture and sequestration only at these types of industrial facilities—and not at other facilities, such as coal-fired power plants—would contribute only marginally to addressing climate change. Specifically, it estimates that CO_2 capture, if widely used at natural gas sweetening facilities, would account for less than 1 percent of CO_2 emissions per year from large stationary sources.

Coal Gasification Technology Offers Promise in Capturing CO_2 at New Plants but Has Limitations That May Impede Its Widespread Use

DOE has pursued gasification technology—specifically IGCC technology—as a key technology for reducing the environmental impact of coal-based electricity generation, and which may be advantageous for CO_2 capture. The gasification process chemically decomposes the fuel before its combustion to provide a stream of CO_2 for separation and storage, as well as a stream of hydrogen for electricity production. It is advantageous in facilitating CO_2 capture because it provides a more concentrated stream of CO_2 at high pressure for separation and reduces the energy required for additional compression of the CO_2 for transport. DOE also indicates that IGCC plants may enable near-zero emissions of pollutants, including sulfur

[16]Howard Herzog and Dan Golomb, "Carbon Capture and Storage from Fossil Fuel Use," *Encyclopedia of Energy*, 2004.

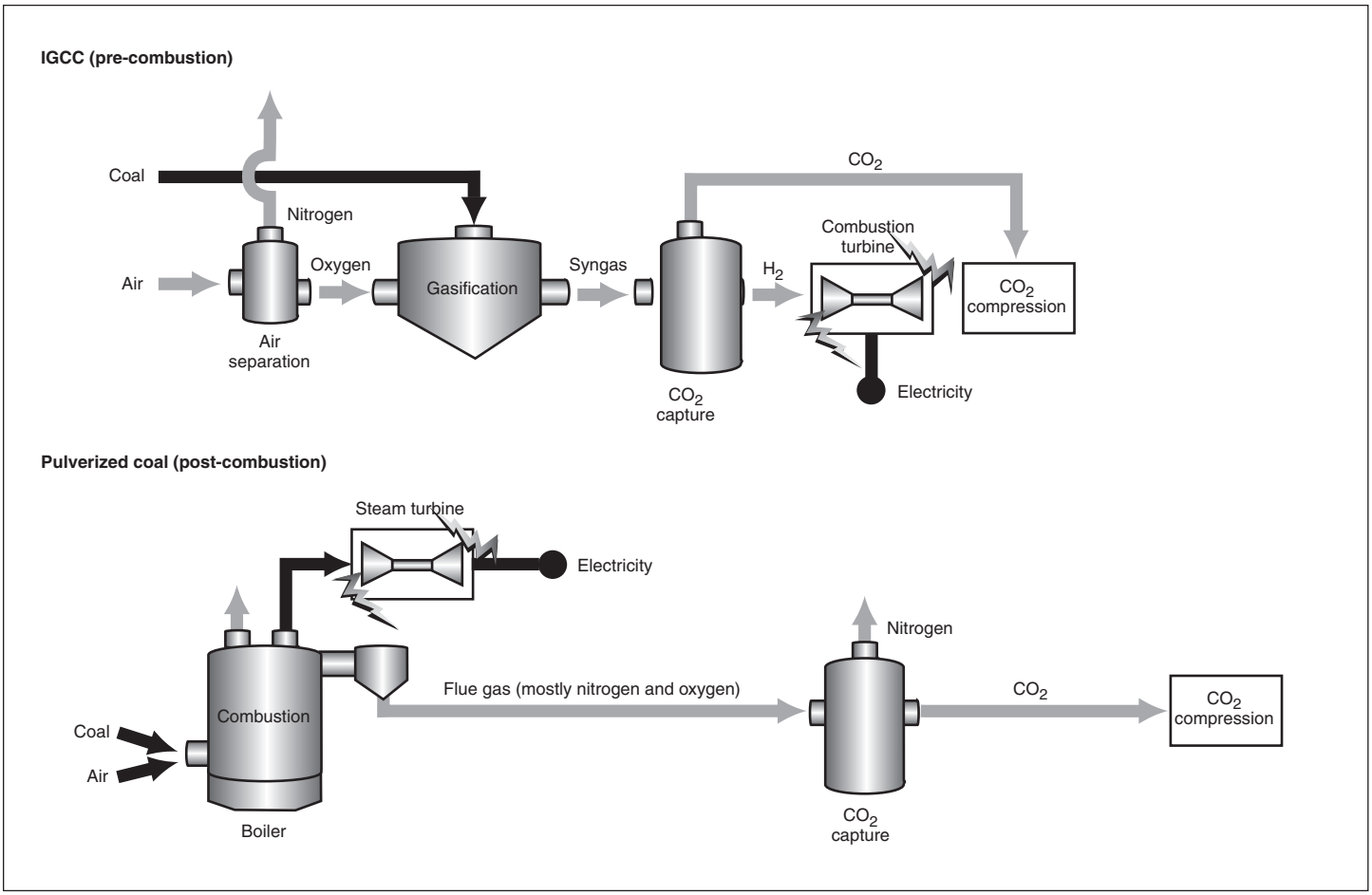
dioxide, nitrogen oxides, and particulate emissions, as well as increase fuel efficiency.

While capturing CO_2 at IGCC plants would impose additional costs, assessments by DOE and international organizations concluded that these costs would be lower than they would be for pulverized coal-fired power plants that remove the CO_2 after fuel combustion. For example, a 2007 DOE study concluded that IGCC plants—if built initially with the capability to capture CO_2 emissions—had a lower adverse impact on efficiency and cost of electricity production than equipping a new pulverized coal-fired power plant and, therefore, were a less expensive option for capturing CO_2 emissions.[17] DOE officials told us that, based on the agency's analysis, the cost of electricity production would increase by 35 percent for newly constructed IGCC plants with CO_2 capture, compared to a 77 percent increase for newly constructed pulverized coal power plants equipped with CO_2 capture.[18] Figure 3 illustrates several of the key differences between the two capture approaches.

[17]Department of Energy, National Energy Technology Laboratory, *Cost and Performance Baseline for Fossil Energy Plants—Volume 1: Bituminous Coal and Natural Gas to Electricity, Final Report* (2007).

[18]DOE officials told us these estimates were based on *Cost and Performance Baseline for Fossil Energy Power Plants—Volume 1.*

Figure 3: Pre-combustion (i.e., IGCC) versus Post-combustion (i.e., pulverized coal) CO_2 Capture



Source: GAO analysis of IPCC and DOE data.

Nonetheless, while IGCC plants using CCS technology have been planned in a number of countries, the outlook for IGCC power plants remains uncertain. Among the factors impeding deployment of the technology are the following:

- *Cost of constructing IGCC power plants.* Recent assessments indicate that it may be initially more expensive to build a new IGCC power plant than to build a pulverized coal power plant if CO_2 emissions are not captured. The IEA notes, in particular, that the investment cost for an

IGCC plant is about 20 percent higher than for a pulverized coal combustion plant.[19] Moreover, the DOE *Cost and Performance Baseline for Fossil Energy Plants* report states that if the power plant does not capture CO_2 emissions, both the total cost of the plant as well as cost of electricity production would be more expensive at the IGCC power plants.[20] Furthermore, the IEA notes considerable uncertainty in IGCC costs because no coal-fired IGCC plants have recently been built.

- *Reliability concerns with IGCC plants*. Several stakeholders we interviewed expressed concern about the reliability of IGCC plants for electricity production. One electric power company official said that existing turbines for IGCC power plants are not reliable enough to provide base-load power for customers at high levels of CO_2 capture. Moreover, according to an MIT study, several IGCC power plants experienced reliability challenges in the first few years of operation, although many of these early problems proved manageable and the reliability of the plants subsequently improved.[21] However, the National Coal Council identifies reliability as one continuing area of concern in which IGCC technology could be improved.[22]

- *Challenges in building new coal-fired power plants in the United States*. Using IGCC as an enabling technology for CCS is premised on building new coal-fired power plants. However, efforts to build new coal-fired power plants, regardless of the technology used, are facing increased regulatory scrutiny due to environmental concerns. A 2008 DOE report, *Tracking New Coal-Fired Power Plants*, states that significantly fewer new U.S. coal-fired power plants have been built than originally planned. Delays and cancellations have been attributed to regulatory uncertainty, including climate change concerns and escalating costs.

[19]International Energy Agency, *Energy Technology Perspectives 2008: Scenarios and Strategies to 2050* (Paris, 2008).

[20]DOE officials told us that the study was based on current technology and not on possible advanced technology being developed.

[21]MIT, *The Future of Coal* (2007).

[22]The National Coal Council, *Technologies to Reduce or Capture and Store Carbon Dioxide Emissions*.

Capturing CO_2 from Existing Coal-fired Power Plants Requires Significant Amounts of Energy and Imposes High Costs

Key assessments indicate that post-combustion capture of CO_2, which would be used at pulverized coal power plants, faces significant technical challenges that greatly affect the cost and feasibility of its deployment using currently available technology.[23] This is significant because these pulverized coal facilities account for an overwhelming share of the world's coal-fired capacity.

In a pulverized coal plant, coal is burned with air in the boiler to produce steam. The steam then drives a turbine to generate electricity. Hence, CO_2 would have to be separated from the boiler exhaust, or flue gas, after combustion, rather than separating the carbon before combustion, as is the case in an IGCC plant. The need to separate CO_2 from the flue gas adds a number of technical challenges that can affect the cost and efficiency of CO_2 capture:

- *Treating large volumes of flue gas to remove CO_2.* As noted earlier, large volumes of flue gas must be treated to remove dilute concentrations of CO_2. DOE estimates that CO_2 accounts for only about 15 percent of the volume of the flue gas from a pulverized coal-fired power plant, compared to about 40 percent in an IGCC plant.

- *Removing impurities from the flue gas before CO_2 removal.* Trace impurities in the flue gas, such as particulate matter, sulfur dioxide, and nitrogen oxides, can reduce the effectiveness of certain CO_2 capture processes. The IPCC notes that it is important to reduce the acidic gas components, which would reduce the absorption capacity of the solvent used to remove CO_2. Additionally, IPCC notes that fly ash and soot present in the flue gas could be problematic, if not addressed.

- *Compressing the captured or separated CO_2.* Compressing captured or separated CO_2 from atmospheric pressure to pipeline pressure represents a large auxiliary power load on the overall plant system. The MIT study indicated that the energy required to compress the CO_2 is the second largest factor in reducing the efficiency of the power plant.[24]

- *Significant cost increases in retrofitting CCS to an existing plant.* An IPCC assessment of several studies concluded that retrofitting a CO_2 capture system to existing coal-fired power plants would increase the

[23]Nearly all existing coal-fired power plants are pulverized coal power plants.

[24]MIT, *The Future of Coal.*

incremental cost of producing electricity from about 150 to 290 percent. Similarly, based on a study of a representative coal-fired plant in Ohio, DOE estimated that capturing 30 percent of a retrofitted plant's CO_2 emissions would increase its cost of electricity production by 2.3 cents per kilowatt-hour, while capturing 90 percent of the plant's CO_2 emissions would increase the cost of producing electricity by nearly 7 cents per kilowatt-hour.[25] For comparative purposes, the DOE's Energy Information Administration reports that the average retail price of electricity in the United States is 8.9 cents per kilowatt hour.

Regulatory and Legal Uncertainties Also Complicate Capture, Injection, and Storage of CO_2

The IPCC, two federal advisory committee reports, and many stakeholders we contacted agreed that key regulatory and legal issues will need to be addressed if CCS is to be deployed at commercial scale. Among these issues are (1) confusion over the rules for injecting large volumes of CO_2, (2) long-term liability issues concerning CO_2 storage and potential leakage, (3) how property ownership patterns may affect CO_2 storage, and (4) how the Clean Air Act will apply to facilities that capture CO_2.

Confusion over Rules about Large-Volume Injections of CO_2

Electric utilities and oil and gas companies have underscored the need for guidance on how CCS projects that inject large volumes of CO_2 would be regulated under EPA's Underground Injection Control (UIC) program, which is designed to protect underground sources of drinking water. As noted earlier, under the UIC program, EPA regulates underground injections of various substances, including nonhazardous and hazardous wastes into more than 800,000 injection wells. The SDWA requires EPA to develop minimum federal requirements for injection practices that protect public health by preventing injection wells from endangering underground sources of drinking water. However, the injection of CO_2 for long-term storage raises a new set of unique issues related to its relative buoyancy, its corrosiveness in the presence of water, and large volumes in which it would be injected.

Stakeholders suggested that the absence of regulations related to large-volume CO_2 injection and storage was creating considerable uncertainty for CCS projects. Recently, EPA proposed a regulation to address this uncertainty. Prior to this proposal, nearly half of the 20 stakeholders we interviewed said uncertainty regarding CO_2 injection and storage regulations was a large or very large barrier to CCS deployment. For

[25]Department of Energy, National Energy Technology Laboratory, *Carbon Dioxide Capture from Existing Coal-Fired Power Plants* (2007).

example, one industry stakeholder said that he was uncertain about whether injecting CO_2 in large volumes was actually legal, since EPA's guidance to date only addresses pilot CCS projects. Other stakeholders have mentioned that without new EPA guidance on large volume CO_2 injections, they were uncertain about how stringent their well construction and monitoring needed to be. In addition, a diverse panel at EPA's 2007 UIC workshop on the issue noted that well spacing could be a significant issue that needed to be addressed, since the pressure effects caused by various CO_2 injections could intersect and have a major impact due to injection volumes, particularly with the size and potential number of CO_2 projects. Finally, according to a 2007 report by the American Public Power Association, the uncertainty associated with UIC permit requirements has complicated commercial scale planning for new coal-fired power plants because it has left utilities uncertain as to whether they could inject CO_2 locally or be required to pipe CO_2 over great distances.

In July 2008, EPA addressed some of these technical and regulatory issues in its proposed rule for underground injection of CO_2 for geologic sequestration. Preliminary stakeholder reaction to EPA's proposed rule, discussed later in this report, suggests that some CO_2 injection-related uncertainties may be headed for resolution through the EPA rulemaking but that others will be more challenging to resolve.

Long-Term Liability Concerns over CO_2 Storage and Possible Leakage

Beyond the immediate concerns over how to inject large volumes of CO_2, stakeholders expressed broader concerns over the long-term liability associated with its storage. They pointed specifically to a lack of clarity regarding who—the injector or the property owner—will ultimately be responsible for CO_2 injections and storage after the wells are capped. If stored CO_2 migrated beyond the area in which it was intended to be stored, there are two potential outcomes that generate concern:

- Stored CO_2 could migrate underground and endanger underground sources of drinking water, leading to liability under the SDWA for the party responsible. According to EPA, CO_2 migration into drinking water can cause the leaching of contaminants, such as arsenic, lead, and other compounds, into the water. CO_2 migration could also result in changes in regional groundwater flow and the movement of saltier fluids into drinking water, causing its quality to degrade. As the July 2008 proposed rule's preamble reiterates, under the SDWA, well operators remain responsible indefinitely for any migration that endangers underground sources of drinking water, and courts could impose civil penalties as high as $25,000 per day. Participants in EPA's 2007 UIC workshop raised the prospect of environmental and health concerns posed by CO_2 injections, including the

mobilization of previously isolated metals, lower pH as a result of CO_2 interaction with water, and saltwater displacement.

- Stored CO_2 could also migrate beneath adjacent lands. If CO_2 was injected for geologic storage and it migrated underground into neighboring mineral deposits, for example, it could interfere with the adjacent mineral owners' abilities to extract those resources, and the injection well's operator could be held liable for nuisance, trespass, or another tort.

  EPA's 2007 UIC workshop, attended by more than 200 stakeholders, revealed liability associated with unintended migration of injected CO_2 to be a critical concern. Similarly, 19 of the 20 stakeholders we interviewed told us that liability related to CO_2 storage was a large or very large barrier to deployment of CCS at commercial scale, with some noting that liability concerns have already negatively impacted companies' ability to initiate CCS projects. For example, two stakeholders reported that these concerns have already made it difficult to obtain insurance for CCS projects. They noted specifically that insurers have difficulty writing insurance policies because of the uncertainties associated with and limited data available for CCS, while another added that investors will not support projects like CCS if they expose them to unlimited and undefined long-term liabilities, especially when future revenue streams are uncertain.

Property Ownership Patterns May Also Affect CO_2 Storage

Setting aside any complications that could later arise from CO_2 leakage onto others' property, electric utilities and other stakeholders note that at the outset of a CCS project, it would be essential to identify and obtain the consent of all surface and mineral property rights owners. Such a determination is not always straightforward because ownership of surface land is often severed from ownership of minerals located below the land's surface and, in the same vein, ownership of saline reservoirs. In these circumstances of severed ownership, state law varies on who owns the geologic formation or potential storage site that would sequester the CO_2. In some states, the surface landowner owns the geological formation, but in others, the mineral rights owner owns the formation. Moreover, those geologic formations used for CO_2 storage that extend below surface lands could encompass the mineral rights of multiple owners.

Aside from the question of who owns the storage site, it is also not clear who would actually own the CO_2 once injected—the injector, the owner of the surface land, or the owner of the subsurface geologic formation—because few state laws or courts have yet to address the issue. Some state laws and courts, however, have recognized that injectors of natural gas retain ownership of that gas.

Multiple stakeholders told us that this issue will be a much larger one as CCS projects are scaled up to commercial scale and move beyond existing enhanced oil recovery projects that inject smaller volumes of CO_2 in order to extract additional oil from underground reservoirs. They noted that the CO_2 plume, or pressure front created by injecting the CO_2 underground, can cover tens to hundreds of square miles, affecting numerous property owners. According to one power company official, this property rights issue is different from liability-related issues, since it could prevent CO_2 from being injected into the ground in the first place. If they cannot get access rights to the formation, they cannot do a project.

Uncertainty Regarding How the Clean Air Act Will Apply to Power Plants with CCS

According to EPA air officials, the Clean Air Act's New Source Review (NSR) requirements apply to new power plants that are constructed with carbon capture technology and may apply to existing power plants that install the technology. NSR is triggered when a new facility is built, or when an existing facility makes a major modification, a physical or operational change that would result in a significant net increase in emissions. Under NSR, permitting authorities review the proposed facility or modification to establish emission limits and ensure the requisite pollution control technologies will be used before granting it a permit. Because of the additional energy required for carbon capture, EPA officials note that power plants implementing the technology might need to burn more coal to generate the same amount of electricity. If this increased coal usage resulted in a significant net increase of emissions of pollutants regulated under the act, such as ozone or sulfur oxide, NSR could be triggered.

Some note that the NSR requirements, and the additional costs and uncertainties associated with them, may discourage facilities such as power plants from adopting CCS technology. For example, a recent report from a federal advisory committee to the Secretary of Energy states that "for existing coal-fired facilities, a major question is whether the Clean Air Act, including the NSR requirements of the Act, would apply if CCS equipment is installed."[26] Multiple stakeholders we interviewed agreed that adding CCS equipment to an existing power plant could raise problems under NSR. One noted, in particular, that NSR challenges were manageable while CCS projects were at the demonstration scale but could pose greater problems when CCS is deployed at a larger scale.

[26]The National Coal Council, The Urgency of Sustainable Coal (Washington D.C., 2008).

The Absence of a National Strategy to Control CO_2 Emissions Gives Neither Industry Nor Government Agencies an Incentive to Invest in CCS

According to the IPCC, the National Academy of Sciences, and other knowledgeable authorities, another barrier is the absence of a national strategy to control CO_2 emissions (emissions trading plan, CO_2 emissions tax, or other mandatory control of CO_2 emissions), without which the electric utility industry has little incentive to capture and store its CO_2 emissions. Moreover, according to key agency officials, the absence of a national strategy to control CO_2 emissions has also deterred their agencies from resolving other important practical issues that will ultimately require resolution if CCS is to be deployed on a large scale. Such issues include lack of clarity regarding who owns injected CO_2 and how stored CO_2 will be addressed in a future emissions trading scheme.

Industry Has Little Incentive to Invest in CO_2 Control Technologies without a National Strategy to Control CO_2 Emissions

A wide range of academic, industry, and other knowledgeable authorities agree that CCS is unlikely to be used to any substantial extent without some kind of national strategy to control CO_2 emissions. The IPCC's 2005 report on CCS observed, for example, that "all models indicate that CCS systems are unlikely to be deployed on a large scale in the absence of an explicit policy that substantially limits greenhouse gas emissions to the atmosphere. With greenhouse gas emission limits imposed, many integrated assessments foresee the deployment of CCS systems on a large scale within a few decades from the start of any significant climate change mitigation regime." It stated further that "the stringency of future requirements for the control of greenhouse gas emissions and the expected costs of CCS systems will determine, to a large extent, the future deployment of CCS technologies relative to other greenhouse gas mitigation options."[27]

EPA's Clean Air Act Advisory Committee's Advanced Coal Technology Workgroup similarly reported that widespread commercial deployment of advanced clean coal technologies, including large-scale CCS, likely will not occur without legislation that establishes a significant long-term "market driver." The majority of stakeholders we interviewed agreed, characterizing the absence of a national strategy to control CO_2 emissions as a large or very large barrier to CCS deployment on a commercial scale, with many stating that without a price on emitting CO_2, there is no rationale for utilities or other facilities to control their emissions. Moreover, according to a leading researcher,[28] "in order for significant

[27]IPCC, IPCC Special Report on Carbon Dioxide Capture and Storage (2005).

[28]J.M. Antle, University Fellow, Resources for the Future, *Is There a Role for Geologic and Terrestrial Carbon Sequestration in Greenhouse Gas Mitigation?* (February 2008).

progress to be made in reducing greenhouse gas emissions, some form of mandatory emissions limits or tax on greenhouse gases will be required, just as in every other area of environmental regulation where substantial costs of emission reductions must be borne."

One indication as to how emitters might respond to a cost on CO_2 emissions was provided by a Norwegian petroleum company after Norway introduced a $40 per metric ton tax on offshore CO_2 emissions in 1991. The Statoil petroleum company's Sleipner project, a natural gas processing project located at a gas field 250 kilometers off the coast of Norway, had already been removing CO_2 from the natural gas to prepare it for sale on the open market. But with no financial incentive to do otherwise, Statoil had simply vented the CO_2 into the atmosphere. At least partly in response to the tax, however, the company, in 1996, began to capture approximately 3,000 metric tons of CO_2 per day from natural gas extraction and store it 800 meters under the North Sea's seabed in a geologic formation called a saline reservoir.

The United States' experience with other pollutants, notably sulfur dioxide (SO_2), also provides insights into the kind of market-based emissions control regime that could emerge if a national strategy to control CO_2 emissions was adopted. In Title IV of the Clean Air Act 1990 Amendments, Congress established a goal of reducing annual emissions of SO_2 by 10 million tons from 1980 emissions levels. Specifically, the law established overall emission limitations and allocated SO_2 emission allowances to individual electric utilities. The utilities are required to own enough allowances at the end of each year to cover their emissions. Under the law's allowance trading system, utilities can trade some or all their allowances in a way that allows them greater flexibility in achieving the required emission reductions at the lowest cost. In cases where utilities were able to reduce emissions below their required allowance, they were able to sell the extra allowances at the market price to other utilities. As with the SO_2 program, analyses by government and academic organizations generally indicate that CCS technology will be more extensively used as emission limits tighten.

An important lesson from the SO_2 program was that as vendors competed to meet utilities' emission reduction needs, they were prompted to seek the least expensive means of providing utilities with low-sulfur coal,

"scrubbers," and other methods for reducing sulfur dioxide emissions.[29] As a result, the overall cost of reducing emissions decreased over time. More generally, a study commissioned by the IEA's Greenhouse Gas R&D Program emphasizes the decrease in costs of new technologies over time.[30] It suggests that for new coal emission control technologies, the initial higher plant costs incurred are gradually reduced through experience and from continued research and development.

The Absence of a National Strategy to Control CO_2 Emissions Has Constrained the Federal Government's Efforts to Plan For and Develop CCS Projects

The absence of a national strategy to control CO_2 emissions not only leaves the regulated community with little incentive to reduce their emissions, it also leaves regulators with little reason to devise the practical arrangements necessary to implement the reductions. For example, regulators have not addressed how utilities that capture and sequester CO_2 would be treated under a future emissions trading plan. The EU's early experience with CO_2 emissions trading illustrates the significance of including CCS in an emissions trading plan. EU officials told us when the Emissions Trading System (ETS) was conceived, the maturity of CCS as a technical reduction option for $CO_2$was not clear. Therefore, CCS projects were not systematically included in the ETS.[31] However, EU officials noted that the situation has changed substantially since then. Indeed, a recent European Commission report indicates that not systematically including CCS in the ETS may be one barrier to its deployment.[32] Accordingly, the European Commission is now proposing legislation to explicitly include, after 2012, facilities involved in the capture, transportation, and storage of CO_2 in the ETS. These facilities would then earn allowances for nonemitted CO_2 and would have to surrender emissions allowances for any leakages of CO_2 that occur. Consequently, EU officials told us that the proposed directive, when enacted, would remove this barrier.

[29]GAO, *Air Pollution: Allowance Trading Offers an Opportunity to Reduce Emissions at Less Cost*, GAO/RCED-95-30 (Washington, D.C.: December 16, 1994) and *Air Pollution: Overview and Issues on Emissions Allowance Trading Programs*, GAO/RCED-97-183 (Washington, D.C.: July 9, 1997).

[30]Edward S. Rubin et al, "Use of Experience Curves to Estimate Future Cost of Power Plants with CO_2 Capture," *International Journal of Greenhouse Gas Control*, vol. 1, issue 2 (2007).

[31]EU member states can seek to include CCS projects in their national emission cap by gaining approval from the European Commission on a case-by-case basis.

[32]EU Commission Staff Working Document, accompanying document to *the Proposal for a Directive of the European Parliament and of the Council on the Geologic Storage of Carbon Dioxide* (January 23, 2008).

Likewise, cognizant agency officials responsible for U.S. programs have told us that they will not act on key CCS implementation issues prior to Congress establishing a national strategy to control CO_2 emissions. For example, as noted earlier, the officials told us that uncertainty regarding property rights ownership stems from ambiguity over who owns the injected CO_2, and it is similarly unclear what the government's potential liability might be for long-term storage of CO_2 on federal lands. Bureau of Land Management (BLM) officials said they are aware of the issue and of the BLM's jurisdiction in the matter but told us they are looking to Congress for a solution before they will take any specific actions to address it. These officials also noted that while they do have authority to permit CO_2 injections on federal lands that are solely for sequestration purposes, they are uncertain whether BLM has statutory authority to establish a funding mechanism for long-term management of sequestration sites on federal lands.

Other practical issues requiring resolution, which cross the jurisdictions of a range of federal agencies and of state and local governments, are discussed later in this report.

Federal Agencies Have Yet to Resolve the Full Range of Issues Requiring Resolution for Widespread CCS Deployment

While federal agencies have begun to address CCS barriers, they have yet to comprehensively address the full range of issues that would require resolution for widespread CCS deployment. DOE has achieved limited results in lowering the cost of CO_2 capture at existing power plants, and the agency's focus on gasification technology to date may not provide for the needed reductions in emissions because few facilities with this technology currently exist. However, DOE's focus has recently shifted to better balance the need for capture technology at both new and existing power plants. EPA has recently issued a proposed rule that clarifies significant regulatory uncertainties related to CO_2 injection and storage. However, critical questions remain about long-term liability for stored CO_2. Elsewhere in the federal government, agencies have not addressed a number of issues that could delay CCS deployment. Among them are how CO_2 pipeline infrastructure might be developed and how a future emissions trading plan would treat avoided CO_2 emissions due to CCS.

DOE Has Only Recently Prioritized Research to Help Control CO_2 Emissions from Existing Power Plants

DOE has identified IGCC technology as the key enabling technology for reducing CO_2 emissions from newly constructed coal-fired power plants and has helped to develop and demonstrate IGCC technology. However, key assessments by the National Academy of Sciences and international organizations have raised questions about how the agency's focus on IGCC technology may have affected the broader effort to substantially reduce CO_2 emissions from coal-based electricity generation because (1) as noted earlier, the outlook for widespread deployment of IGCC technology is questionable and (2) the agency's funding related to IGCC technology has substantially exceeded funding for technologies more applicable to reducing emissions from existing coal-fired power plants. DOE has recently started to focus greater attention on technologies more applicable to reducing emissions from existing power plants.

DOE Has Achieved Some Advances with IGCC Technology

Consistent with DOE's emphasis on IGCC, the agency cites a number of accomplishments in advancing the technology, such as its support for two operational IGCC power plants, in Florida and Indiana, that produce substantial amounts of electricity, while also demonstrating the production of high-pressure syngas amenable to CO_2 capture.[33] DOE also cites its contributions to the development of several IGCC-related technologies, which would advance pre-combustion CO_2 capture. Specifically, recent technological advances cited by the agency include successful fabrication and testing of a liquid membrane that is stable at high temperatures and that could be used for CO_2 capture in IGCC plants, as well as a new material with CO_2 separation potential for gas separation. Moreover, according to a published journal article with three DOE co-authors, advances in membranes may be significant in advancing CO_2 capture because membranes are less energy intensive, compared to other separation techniques.[34] Taken together, the National Academy of Sciences credits DOE's efforts in promoting IGCC technology, citing the agency's

[33]Syngas is the gas produced by the gasification process, composed of hydrogen, carbon monoxide, and minor amounts of other constituents. While DOE considers the gas stream amenable to CO_2 recovery, CO_2 capture was not actually demonstrated in the projects.

[34]Jose D. Figueroa, Timothy Fout, Sean Plasynski, Howard McIlvried, and Rameshwar D. Srivastava, "Advances in CO_2 capture technology- The U.S. Department of Energy's Carbon Sequestration Program," *International Journal of Greenhouse Gas Control*, vol. 2 (2008).

efforts to develop "a close working relationship with the industry to move the technology through the commercial demonstration stage."[35]

Looking ahead, DOE hopes to make further investments, and progress, in demonstrating IGCC's feasibility to capture CO_2 through its FutureGen program, which aims to accelerate commercial deployment of IGCC or other advanced clean coal-based power generation technology with CCS. Moreover, under the restructured FutureGen program, DOE anticipates supporting demonstrations at more than one site.

DOE Funding Decisions Reflect Agency's Focus on IGCC

DOE's progress, however, has required both significant time and resources. As the National Academy of Sciences noted, the development of an integrated IGCC system has been an important component of DOE's Fossil Energy Research Development and Demonstration program for more than 20 years, and between 1978 and 2000, DOE invested $2.3 billion in gasification technology.[36] Moreover, DOE budget data indicate that in more recent years, the agency has continued to provide substantial funding for IGCC technology. Several Fossil Energy programs provide substantial support for developing IGCC technology, including the IGCC program, the FutureGen program, and the advanced turbines program. Together, these programs account for a significant share of Fossil Energy's overall budget. The Carbon Sequestration program also provides some additional funding for CO_2 capture using IGCC technology.

Developing an exact estimate of DOE funding for IGCC technology is challenging because the individual DOE programs pursue multiple objectives and funding categories have changed over time. However, an examination of DOE's budget information suggests that its support from 1997 (the year the Carbon Sequestration program began) to present is likely on the order of hundreds of millions of dollars and probably in excess of $500 million. A DOE official within Fossil Energy acknowledged to us that "the bulk of coal program capture funding relates to gasification, particularly IGCC," although DOE officials said they are now focusing more attention on existing pulverized coal power plants.

[35]National Research Council, National Academy of Sciences, *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000* (Washington, D.C., 2001).

[36]National Academy of Sciences, *Energy Research at DOE: Was It Worth It?*

IGCC Technology's Potential for Reducing CO_2 Emissions Is Uncertain

The payoff for this investment, however, will depend heavily on the extent to which IGCC technology is used in newly constructed power plants—both in the United States and worldwide. In this regard, the National Academy of Sciences said in a recent assessment that the Carbon Sequestration program "is taking on a relatively high overall risk to create technologies for commercial demonstration by 2012 in that it relies heavily on the successful deployment of full-scale IGCC plants." The report added that there are only a few IGCC plants operating worldwide and advanced, commercial-scale IGCC units are only in the design phase and have no CO_2 sequestration.[37]

Moreover, as noted earlier, studies by the IEA, DOE, and the National Coal Council cite a number of compelling factors, such as the relative cost of IGCC plant construction and the limited operational experience worldwide with this relatively new technology, which may limit commercial deployment of IGCC technology. Several industry stakeholders we interviewed expressed concerns about using IGCC technology for electricity generation, including the cost of constructing IGCC plants and possible reliability concerns. For example, officials from one electric power company told us they thought high levels of CO_2 capture at IGCC plants would necessitate the use of a turbine, which has not yet been commercially demonstrated. Looking ahead, the IEA's 2007 *World Energy Outlook* notes that "for IGCC to establish itself in the market, further development to bring down costs and improve operational flexibility is necessary."

DOE Has Thus Far Achieved Limited Success in Reducing CO_2 Emissions from Existing Power Plants

Until recently, DOE budget decisions reflected a view that IGCC technology offered greater potential to capture CO_2 than technologies applicable to pulverized coal-fired power plants. As indicated earlier, DOE budget information we reviewed indicates substantial funding for IGCC technology, likely in the order of hundreds of millions of dollars. By comparison, DOE support for post-combustion CO_2 capture technology, most applicable for existing plants, appears more limited, likely on the order of tens of millions of dollars.

As noted earlier, DOE has cited a number of challenges that complicate efforts to capture CO_2 emissions from pulverized coal-fired power plants,

[37]National Research Council, National Academy of Sciences, *Prospective Evaluation of Applied Energy Research and Development at DOE (Phase Two)* (Washington, D.C., 2007).

including the large volumes of gas that must be treated; trace impurities in the exhaust gas (such as particulate matter, sulfur dioxide, and nitrogen oxides) that can degrade the effectiveness of certain capture processes; and the high amount of energy needed to compress CO_2 emissions. Among other things, a DOE study concluded that if CO_2 capture were added to a pulverized coal-fired power plant that started operations in 2010, its cost of electricity production would increase by approximately 80 percent.[38]

These technological realities, however, are at odds with another reality anticipated by a number of organizations: these facilities will account for the vast majority of coal capacity in the United States and around the world in the near term. Accordingly, in past years, the agency has undertaken some initiatives to advance technologies to capture CO_2 from these facilities and points to a number of accomplishments arising from these efforts. Among them, DOE researchers reported patenting a technique to capture CO_2 from a coal-fired power plant's exhaust using ammonia, a technique planned for two capture demonstrations at power plants in Ohio and North Dakota. DOE officials also point to several other projects related to post-combustion CO_2 capture, including development of ionic liquids with greater absorption capacity for CO_2 and development of sorbent technology for retrofitting existing pulverized coal plants. DOE officials also pointed to investments in two other challenging aspects of CO_2 capture. One involves research to address one of the largest cost drivers, the cost of regenerating the absorbent. DOE officials also pointed to work on technologies to improve the efficiency of compressing CO_2, a major cost factor in capturing CO_2 at these facilities.

Nonetheless, DOE's own analysis raises questions concerning the agency's progress in helping to reduce the cost of CO_2 capture at pulverized coal power plants. For post-combustion CO_2 capture, DOE officials indicated to us that the agency's current goal is to develop, by 2012, pilot-scale systems to capture 90 percent of CO_2 at no more than a 35 percent increase in the cost of electricity production. However, it is noteworthy that this goal is to develop pilot-scale systems only; commercial-scale units will not come online until the 2020 time frame.

An assessment report recently published by DOE indicates the size of the challenge DOE faces in reducing the cost of capture. The study indicated that CO_2 capture would increase the cost of electricity production by 77

[38]DOE, *Cost and Performance Baseline for Fossil Energy Plants—Volume 1.*

percent at a pulverized coal power plant starting operation in 2010.[39] A DOE official within Fossil Energy acknowledged to us that owners of existing pulverized coal power plants, under a future emissions trading arrangement, might choose to purchase carbon allowances, rather than pay for an expensive retrofit, and that plant age and other economic considerations will make the determination of whether a retrofit or another action, such as purchasing allowances, will occur.

One contributing factor to DOE's limited progress in reducing CO_2 emissions from existing power plants is that it is a relatively lower priority for DOE. The National Academy of Sciences noted that the Carbon Sequestration program has focused on IGCC technology to achieve its goal of reducing the cost of carbon capture.[40] Our examination of DOE's budget in recent years supports this view:

- *The Carbon Sequestration program has provided limited capture funding*: DOE officials estimated the Carbon Sequestration program provided approximately $50 million in funding related to all types of CO_2 capture from fiscal year 2002 to fiscal year 2007. While DOE officials were able to provide limited information quantifying precisely how this funding was split between post-combustion and pre-combustion capture, they indicated that the majority of it went toward the development of post-combustion and oxy-combustion capture technologies. DOE officials suggest that, historically, 20 percent of the Carbon Sequestration program's budget has gone toward capture, which DOE officials said allowed capture technology development to continue as DOE evaluated geologic storage of CO_2. However, capture-related funding has generally received less funding in the Carbon Sequestration program's budget than other areas, such as the regional partnerships.

- *Post-combustion capture has not been supported by related programs*: Until recently, post-combustion CO_2 capture had not received large amounts of funding from other programs in Fossil Energy. Specifically, until fiscal year 2008, no other major Fossil Energy programs provided substantial funding related to post-combustion capture, in contrast to those programs' support for IGCC technology.

[39]DOE, *Cost and Performance Baseline for Fossil Energy Power Plants—Volume 1.*

[40]National Academy of Sciences, *Prospective Evaluation.*

DOE Has Recently Focused More Attention on Existing Plants

Looking ahead, DOE officials told us that the agency is now focusing more attention on reducing CO_2 emissions from existing plants by shifting the focus of a related Fossil Energy program, the Innovations for Existing Plants program, so that it emphasizes the development of post-combustion capture of CO_2. Among the factors cited in this decision were (1) the large number of pulverized coal power plants in the United States; (2) congressional direction in the report accompanying the agency's fiscal year 2008 appropriation to focus more attention on this issue; and (3) the applicability of advances in this area to the large number of pulverized coal power plants under construction in China and India.

In February 2008, DOE announced that it was soliciting applications for projects "specifically focused on developing technologies for CO_2 capture and separation that can be retrofitted to existing pulverized coal (PC) power plants." In July 2008, the agency announced it was providing $36 million in funding for 15 projects to develop new and cost-effective capture technologies for existing power plants.

Other recent changes in DOE's funding decisions also appear to recognize the significance of reducing emissions from existing power plants:

- The Carbon Sequestration program's funding for post-combustion CO_2 capture (including oxyfuel combustion capture) increased from $10.1 million in fiscal year 2007 to $15.4 million in fiscal year 2008.

- The network of Regional Carbon Sequestration Partnerships appears to be placing more emphasis on demonstrations of CO_2 capture at coal power plants for an upcoming series of large-scale sequestration projects. Specifically, a DOE official identified three projects being planned to capture CO_2 from coal-fired power plants, including possibly capturing 500,000 tons of CO_2 from a coal-fired power plant in North Dakota.

- DOE indicated in an August 2008 announcement that the agency's Clean Coal Power Initiative program would support coal-based technologies to capture and sequester CO_2 emissions. For post-combustion CO_2 capture, the announcement indicated that advanced technologies are sought to reduce the cost and additional power load of CO_2 capture.

While it seems too early to evaluate the results of DOE's increased focus on post-combustion CO_2 capture, key organizations' assessments appear supportive of this shift. A 2008 National Coal Council report, for example,

identifies retrofitting existing coal power plants with CCS as part of a larger approach to reducing emissions.[41] In the same vein, the IPCC notes that the strategic importance of post-combustion capture systems becomes evident when one considers the large amount of emissions from pulverized coal power plants.

EPA Has Begun to Address Regulatory Uncertainty Concerning CO_2 Injection and Storage, but Key Issues Remain Unresolved

As discussed earlier in this report, CCS stakeholders have stated that the absence of regulations governing large-volume CO_2 injection and storage had created considerable uncertainty about the projects and risks associated with CCS. In an effort to address many of these concerns, EPA issued a proposed a rule in July 2008 to address permitting and other requirements for injection of CO_2 for geologic sequestration. The proposed rule, issued under the agency's SDWA authority, clarifies a number of practical issues for prospective well owners and operators concerning CO_2 injection and identifies certain requirements governing their financial responsibilities, including for the period after the CO_2 is injected and the well is closed. However, as EPA officials note, the rulemaking was not intended to resolve many questions concerning how other environmental statutes may apply to captured and injected CO_2, including the Clean Air Act, CERLCA, and RCRA. A number of key issues, therefore, have yet to be addressed.

EPA Has Issued a Proposed Rule under the SDWA on Permitting Large-Volume CO_2 Injections

EPA's July 2008 proposed rule creates a new "Class VI" well type for injection of CO_2 for geologic sequestration. In doing so, it clarifies a number of issues relating to the more immediate, practical issues regarding CO_2 injection for geological storage. However, some notable ambiguities remain, particularly in the area of longer-term financial responsibility requirements. The following summarizes both the issues that have been addressed and those which may still need to be clarified. In the discussion below, we provide the preliminary views of the stakeholders we interviewed. It is important to note, however, that the proposed rule's 120-day comment period runs until November 24, 2008, during which time EPA will obtain a broader array of public advice and opinions on its proposed rule.

Site characterization, well construction, and monitoring requirements. The proposed rule specifies a number of requirements concerning the location of the CO_2 injection well, including (1) the criteria for

[41]The National Coal Council, *The Urgency of Sustainable Coal.*

characterizing the site of the geologic formation and (2) requirements for reviewing the wider geographic area surrounding the storage site prior to injection. Regarding site characterization, the well owner or operator must demonstrate that the well will be located in an area with a suitable geologic system, including a confining zone for the injected CO_2 that is free of faults or fractures, that would contain the CO_2. The proposed rule also specifies that injection of CO_2 above the lowermost formation containing an underground source of drinking water is prohibited. Regarding the wider geographic area surrounding the storage site that may be impacted by the injection, it requires well owners and operators to delineate an Area of Review (AoR) within which the owner or operator must identify all penetrations, such as wells, that may penetrate the confining zone and determine whether the wells have been plugged in a manner that prevents the movement of CO_2 or associated fluids that may endanger underground sources of drinking water.

The proposed rule also includes standards for well construction, operation, and monitoring. For example, although EPA does not specify which materials must be used, the proposed rule does require the use of materials that meet or exceed industry standards, that are compatible with injected CO_2, and that are designed for the life of the well. The proposed rule also contains an injection pressure limitation so that an injection does not create new fractures or cause movement of injected CO_2 that endangers underground sources of drinking water. It requires continuous monitoring of injection pressure, rate, and volume, and requires semiannual reporting of this data to EPA. The proposed rule also requires well owners and operators to submit, with their permit application, a testing and monitoring plan to verify that the CO_2 storage project is operating as permitted and is not endangering underground sources of drinking water.

The proposed rule also addresses stakeholder concerns about how current CO_2 injection wells operating as Class I industrial wells, Class II injection wells that use CO_2 for enhanced oil or natural gas extraction, and Class V experimental CO_2 injection wells would be regulated if they transition to use for long-term storage. It specifies that owners of these existing wells may apply for the new Class VI permit and that the UIC program director would have the discretion to grandfather the well's pre-existing construction requirements if the director determined that doing so would not endanger underground sources of drinking water. With this exception, the project would have to meet all other Class VI requirements in order to obtain a Class VI permit.

Financial responsibility requirements. EPA's proposed rule specifies that well owners and operators must demonstrate and maintain financial responsibility for corrective action (that is, repairs or other actions necessary to assure that wells within the AoR do not serve as conduits for the movement of fluids into underground sources of drinking water), well plugging, post-injection site care for a period of 50 years following cessation of injections, site closure, and emergency and remedial response. The UIC program director can adjust the 50-year time period for post-injection site care depending on whether the project poses an endangerment to underground sources of drinking water. If the UIC program director chooses to lengthen the post-injection site care time period, the owner and operator must continue to demonstrate financial responsibility until the end of that period. Although the financial responsibility demonstration requirement ends when the post-injection site care time period does, the proposed rule's preamble indicates that well operators remain responsible indefinitely for any endangerment of underground sources of drinking water.

In addition to clarifying well site care, the proposed rule also requires that well owners and operators periodically update their cost estimate for corrective action, well plugging, post-injection site care and site closure, and emergency and remedial response, and that they redemonstrate financial responsibility for these increased costs as the UIC program director deems necessary. It also requires well owners and operators to notify the UIC program director of any adverse financial conditions they encounter, such as bankruptcy.

While stakeholders acknowledge EPA's progress in clarifying some key financial responsibility requirements, they cite several other concerns:

- Although EPA's proposed rule establishes a post-injection site care period, it does not include a provision allowing well operators to be released from liability for endangerment of underground sources of drinking water during the hundreds of years that CO_2 will be stored in a geologic storage project. While it is beyond EPA's authority to release injection well owners and operators from liability, a discussion of long-term liability is included in the proposed rule's docket. Stakeholders told us that they were concerned by the unspecified period of time for which they may be liable for stored CO_2.

- The proposed rule only specifies a duty to demonstrate financial responsibility, stating that guidance will be developed at a later date describing the types of financial mechanisms that owners or operators can

use. Currently, financial responsibility for other well classes is demonstrated through third-party instruments, such as a surety bond that establishes a trust fund, or self-insurance instruments, such as a corporate financial test. However, EPA's existing financial responsibility requirements have been criticized as inadequate and the agency is currently reviewing its approach. EPA is evaluating whether to revise its financial responsibility guidance in light of these criticisms and is seeking public comments on various financial responsibility topics. Moreover, EPA officials told us that the Miscellaneous Receipts Statute limits the financial responsibility regulations because it prevents EPA from requiring a cash deposit or receiving money as a trustee.[42] The proposed rule's preamble also notes that EPA does not have the statutory authority to transfer financial responsibility from the well owner or operator to a third party.

Finally, there is some question as to whether EPA will have sufficient resources to implement the expanded UIC program. EPA has not examined the level of resources that will be needed to administer the UIC program once commercial-scale deployment of CCS occurs. However, a 2007 report by DOE's Argonne National Laboratory did examine the issue and concluded that if CO_2 were stored in large enough volumes to have a meaningful impact on global warming, it is likely that thousands or tens of thousands of injection wells would need to be developed and permitted in the United States. The report noted that this would require that state and regional UIC programs expand their staff and capabilities. In this connection, it observed that the annual national budget for the UIC program—approximately $11 million—has remained static for many years, even as UIC agencies have been asked to take on additional responsibilities. It warned that failure to provide sufficient resources would likely create permitting backlogs, resulting in a bottleneck in the overall carbon sequestration effort.

Multiple stakeholders agreed that EPA needs additional resources for the UIC program, including permit writers. One industry representative expressed concern that it can take up to 2 years to obtain a permit for a well under EPA's UIC program, and that if CCS projects become more widespread, EPA will be responsible for permitting thousands of additional injection wells.

[42] 31 U.S.C. § 3302(b).

Key Legal and Regulatory Issues outside of the SDWA Have Been Largely Unaddressed

While EPA has addressed at least some of the legal and regulatory issues on how CO_2 injectors are to protect underground sources of drinking water, it has thus far not resolved a number of key environmental issues that fall under the jurisdiction of other statutes, including the Clean Air Act, RCRA, and CERCLA.

Clean Air Act. As noted earlier, the Clean Air Act's New Source Review (NSR) requirements could be triggered if an existing facility's installation of capture technology makes a major modification that significantly increases emission of regulated pollutants. EPA officials acknowledge concerns that NSR could cause delays and impose added costs to CCS projects. However, they said that an assessment of how NSR might impact the feasibility of CCS projects cannot be made globally because it depends on site-specific factors, such as geological and hydrological considerations, the CCS technology that will be used, how it will operate, and how that operation could affect the rest of the plant.

Laws governing hazardous wastes and substances. RCRA and CERCLA could pose similar complications for CCS projects. RCRA authorizes EPA to establish regulations governing the treatment, storage, and disposal of hazardous waste. A hazardous waste is generally defined as a solid waste that either (1) exhibits certain characteristics (ignitability, corrosivity, reactivity, or toxicity) or (2) has been listed as a hazardous waste by EPA. CERCLA established the Superfund program to clean up sites that have been contaminated by hazardous substances. CERCLA authorizes EPA to compel the parties statutorily responsible for the hazardous substances to bear the costs of cleaning up the contaminated site or to carry out cleanups itself and recover costs from the responsible parties. Hazardous substances are those which may present substantial danger to the public health, welfare, or environment when released and include all hazardous wastes subject to RCRA.

Whether any given injected CO_2 stream is categorically a hazardous waste or hazardous substance has not been resolved by EPA. The preamble to EPA's proposed rule notes that pure CO_2 in and of itself is not listed as a hazardous substance under CERCLA. However, the rule's preamble cautions that injected CO_2 streams could contain hazardous constituents that would make these streams "hazardous."[43] It notes that since the

[43]The proposed rule's preamble notes that if a CO_2 stream contains hazardous waste as a constituent, it must be permitted as a Class I well. Class I wells are intended for hazardous materials.

chemical composition of individual injected CO_2 streams vary, no categorical determination can be made as to whether all injected CO_2 streams are hazardous wastes. Accordingly, the preamble says that it will be up to the well owners and operators to make this determination on the basis of their particular circumstances. EPA officials said that they lacked the information about the composition of CO_2 streams captured from coal-fired power plants necessary to determine whether those streams should categorically be listed as a hazardous waste under RCRA.

Thus, considerable uncertainties over how owners and operators of CCS projects would be treated under key environmental laws other than the SDWA remain unresolved. An EPA federal advisory committee working group had emphasized, in particular, that the EPA address the liability implications concerning CO_2 injection under RCRA and CERCLA.[44] However, the proposed rule is unclear as to whether the two laws even apply to injected CO_2, and it is therefore uncertain whether injectors will be subject to hazardous waste disposal requirements and liability for hazardous substance releases.

Other Key Issues That Should Be Proactively Addressed to Support a National CCS Framework

In addition to the technical and legal issues affecting CCS's prospects, key studies, federal advisory committees, and the stakeholders we interviewed also identified an array of other issues that would need to be resolved if the technology is to be deployed within a time frame scientists believe is needed to address climate change. Moreover, whereas many of the technical and regulatory issues discussed earlier fall within the domain of two agencies (DOE and EPA), these other issues cross the jurisdictions of the Departments of the Interior and Transportation, the Federal Energy Regulatory Commission, and other agencies in a manner that would require collaboration between agencies and, in many cases, coordination with state governments and other entities.

Property Rights and Liability Issues Related to CO_2 Injection on Both Federal and Nonfederal Lands

Under a national CCS program, CO_2 could be sequestered on both federal and nonfederal lands and would raise complex property rights issues needing resolution in both instances. In the case of federal lands, BLM, which manages the federal government's mineral resources, is required by

[44] Clean Air Act Advisory Committee Advanced Coal Technology Work Group, Final Report of the Advanced Coal Technology Work Group (Jan. 29, 2008).

the Energy Independence and Security Act of 2007[45] to report by December 2008 on a framework to manage geological carbon sequestration activities on public lands. According to BLM officials, the report will include a discussion of the unresolved property ownership and liability issues related to long-term CO_2 storage. They note that the report will also discuss the statutory authority BLM currently has and what it lacks, such as the authority to establish a funding mechanism for monitoring and mitigation efforts associated with sequestration sites. They cautioned, however, that the report will not recommend solutions to current uncertainties and explained that since injected CO_2 can move onto adjacent private or state lands, resolving them will require collaboration with private landowners and state agencies.

Nationwide CO_2 sequestration would also pose major challenges on nonfederal lands. EPA notes that states with primacy for the UIC program have typically addressed such challenges when they have arisen under that program. The agency acknowledged the additional complications that would arise as stored CO_2 crossed state boundaries, but noted that such cross-jurisdictional issues typically occur under the UIC program and that states have worked together to address them. Nonetheless, the significantly larger scale of a future CCS program could magnify the problems posed by these jurisdictional issues. EPA officials noted that they are hoping that the proposed rule's comment process will surface ideas to address these problems. However, EPA officials also note that the agency lacks authority to issue regulations resolving these issues.

Furthermore, while EPA's proposed rule reaffirms liability related to underground sources of drinking water, ambiguity remains regarding who—the injector or the property owner— is ultimately responsible for unanticipated releases of the injected CO_2 that have other effects. As discussed earlier, the released CO_2 could interfere with the adjacent mineral owners' abilities to extract those resources, and the injection well's operator could be held liable for nuisance, trespass, or another tort.

CO_2 Pipeline Regulation

Pipelines are the preferred method of transporting large amounts of CO_2. The Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) administers safety regulations for CO_2 pipelines that affect interstate commerce and certifies states that have adopted regulations compatible with the minimum federal safety

[45]Pub. L. No. 110-140 (2007).

standards to regulate their intrastate pipelines. No federal agency has claimed jurisdiction over siting, rates, or terms of service for interstate CO_2 pipelines.[46] However, early assessments indicate that a nationwide CCS program could require a network of interstate CO_2 pipelines that would raise cross-jurisdictional issues and involve multiple regulatory authorities—all in the unprecedented context of a nationwide program to transport massive volumes of CO_2.

Neither the Federal Energy Regulatory Commission (FERC) or Surface Transportation Board (STB) currently regulate interstate CO_2 pipelines and have not developed any guidance for possible regulation because, according to agency officials, neither agency has statutory authority to do so. FERC has the statutory authority to regulate the siting, rates, and terms of service for interstate pipelines transporting natural gas, which is defined as "natural gas unmixed or any mixture of natural and artificial gas."[47] FERC has interpreted this statutory language to mean a gaseous mixture of hydrocarbons that is used as a fuel.[48] According to FERC officials, under this interpretation, CO_2 pipelines fall outside of the commission's jurisdiction.[49] According to the FERC Chairman's congressional testimony, he would not recommend that Congress preempt the states on CO_2 pipelines because state siting has not been a failure, unlike the situation that led to federal preemption of natural gas pipeline siting.[50] FERC officials noted that the commission could have a prospective role in regulation of CO_2 pipelines, which could be modeled on its natural gas transport and storage work, but that it would need statutory authority to take such a role.

The STB has statutory jurisdiction over pipelines that transport a commodity "other than water, gas, or oil."[51] STB's predecessor, the

[46]FERC has jurisdiction over interstate pipelines that transport oil or natural gas. STB has jurisdiction over interstate pipelines that transport a commodity other than water, gas, or oil.

[47]15 U.S.C. § 717a(5).

[48]Cortez Pipeline Company, 7 F.E.R.C. ¶ 61,024 (1979).

[49]*Id.*

[50]Testimony of the Honorable Joseph T. Kelliher, Chairman, Federal Energy Regulatory Commission, before the Committee on Energy and Natural Resources, United States Senate, January 31, 2008.

[51]49 U.S.C. § 15301.

Interstate Commerce Commission, interpreted its organic statute as excluding all gas types (including CO_2), regardless of origin or source, from its jurisdiction.[52] Therefore, the commission concluded that it lacked jurisdiction over interstate CO_2 pipelines. STB staff told us that if a party sought reconsideration of the prior decision disclaiming jurisdiction over interstate CO_2 pipelines, the board would consider re-examining the commission's earlier decision.

While neither FERC nor STB has developed guidance for the regulation of interstate CO_2 pipelines, the stakeholders we interviewed had differing views on whether federal regulation of CO_2 pipelines should be expanded. Several stakeholders thought it would be necessary for the federal government to take a more active role in siting issues and CO_2 pipeline rates. On the other hand, several other stakeholders expressed concern that expanding federal regulation could have unintended consequences. For example, one industry stakeholder told us that regulating pipeline rates could discourage investment in new pipelines.

Other factors may need to be considered for CO_2 pipelines that cross federal lands managed by BLM. According to stakeholders, one key question will be whether new CO_2 pipelines should operate as common carriers under federal law. As common carriers, pipelines' terms of service would need to be just, reasonable, and nondiscriminatory. Under the Federal Land Policy Management Act, BLM has the authority to grant rights-of-way for pipelines across federal lands but not to require them to operate as common carriers. In addition, BLM officials told us they are not assessing the rights-of-way on federal lands for CO_2 pipelines because their current statutory authority for rights-of-way is sufficient.

DOE's Southwestern and West Coast Regional Carbon Sequestration Partnerships are presently conducting a CO_2 pipeline study, in conjunction with MIT and Sandia National Laboratories, which may inform the discussion about future CO_2 pipelines. According to DOE officials, the report will be issued next year. The officials note that it is not clear whether the report will address all of the relevant issues, including regulatory jurisdiction and siting decisions.[53]

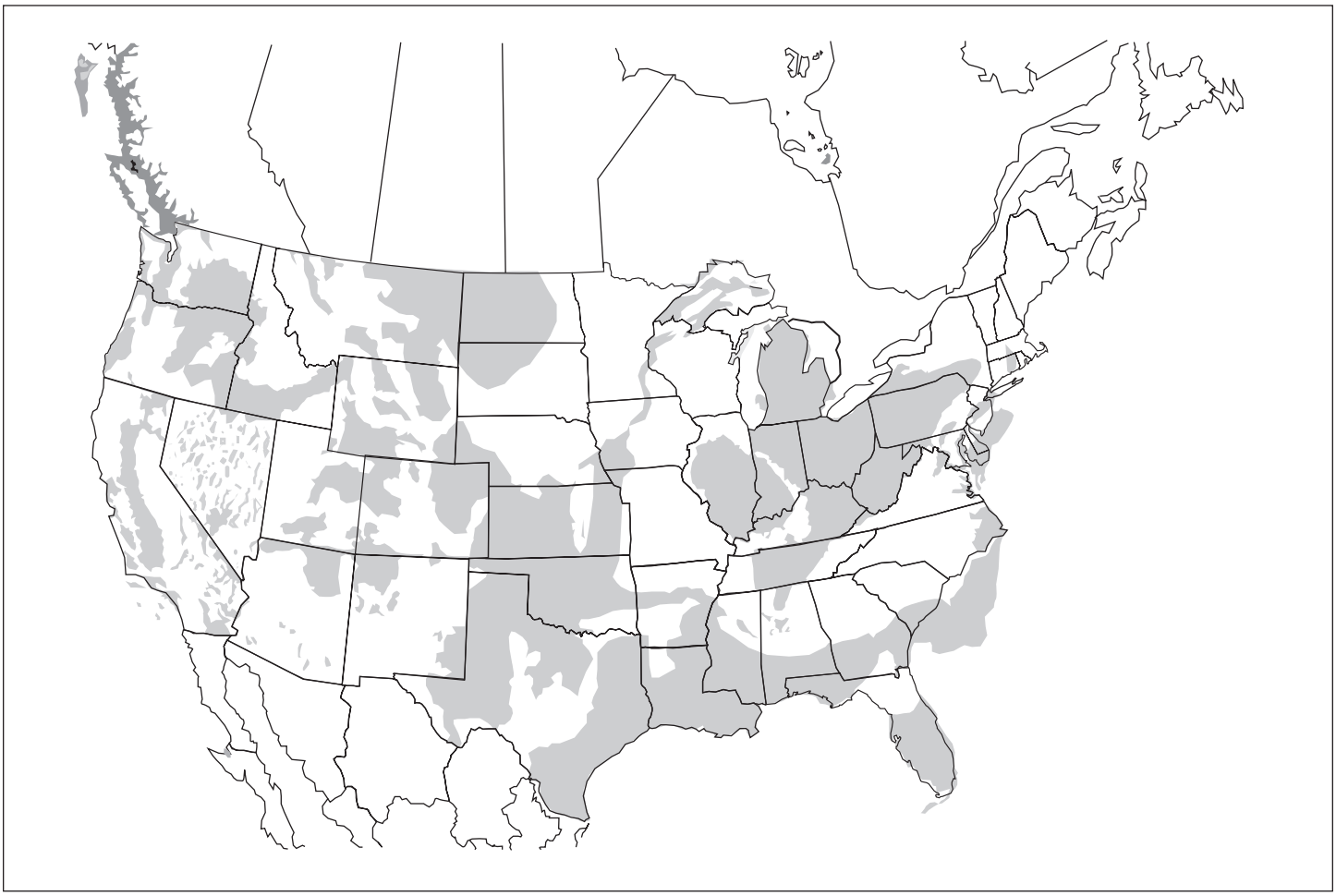
[52]45 Fed. Reg. 85,178 (Dec. 24, 1980); 46 Fed. Reg. 18,805 (Mar. 26, 1981).

[53]DOE officials note that several of the Regional Partnerships, including the Southwest, West Coast, Southeast, Midwest, and Plains CO_2 reduction partnerships, have completed or are working on pipeline studies for their individual regions.

Detailed Assessment of Feasible CO_2 Storage Sites

In recent years, DOE has worked with state geologic survey offices and other partners to construct a national carbon sequestration geographic information system that provides information that can be used to evaluate the potential for CO_2 geologic sequestration across the United States. However, knowledgeable authorities agree that a more detailed evaluation of these sites' actual capacity is needed. As figure 4 shows, the geology of much of the United States may be well suited for CO_2 sequestration. However, a more detailed evaluation would determine whether these potential sites are actually appropriate for long-term CO_2 sequestration. For example, it is currently not known whether the caprock overlying these geologic formations is sufficient to contain stored CO_2.

Figure 4: Potential Geologic Storage in the United States



Source: GAO analysis of DOE data.

The Energy Independence and Security Act of 2007[54] requires the U.S. Geological Survey (USGS) to develop a methodology for, and conduct an assessment of, the capacity for sequestration of CO_2 in the United States. USGS officials explained that their approach will be to explore geologic formations at the individual sedimentary basin level, and they will take storage integrity and injectivity into account. They plan to begin with oil and gas reservoirs because these are the most familiar geologic formations

[54]Pub. L. No. 110-140 (2007).

in terms of the integrity of the reservoirs and their ability to store CO_2. USGS officials will then assess saline formations, about which less data are available. According to USGS officials, the methodology should be completed by March of 2009, at which time it will be released for external technical review and public comment. Following any needed revisions to the methodology and receipt of funding, the USGS will proceed with the actual assessment.

Potential Public Opposition Arising from Health Concerns over CO_2 Storage and Transport

According to the preamble to EPA's proposed rule, improperly operated injection activities or ineffective long-term storage could result in release of injected CO_2 to the atmosphere, resulting in the potential to impact human health. EPA's summaries of stakeholder workshops indicate that public health concerns have been expressed about such issues. One concern is the risk that improperly operated injections could result in the release of CO_2, and that at very high concentrations and with prolonged exposure, CO_2 can lead to suffocation. Concerns have also been raised that improperly injected CO_2 could raise the pressure in a geologic formation and, if it became too high, could cause otherwise dormant faults to trigger seismic events, such as earthquakes. The IPCC has noted, however, that 99 percent of the CO_2 stored in appropriately selected and managed formations is very likely to be retained for over 100 years,[55] and EPA states in the preamble to its proposed rule that the risk of asphyxiation and other health effects from airborne exposure to CO_2 resulting from injection activities is minimal.

Thus far at least, there has been little public opposition to the CO_2 injections that have taken place in states such as Texas to enhance oil recovery. However, several notable studies explain that this lack of publicly-expressed concern may reflect more a lack of knowledge about CCS rather than confidence that the process is safe.[56] This is suggested in the IPCC's 2005 report on CCS which stated, for example, that there is insufficient public knowledge of climate change issues and of the various mitigation options and their potential impact. In another 2005 study, researchers surveyed 1,200 people, representing a general population sample of the United States, and found that that less than 4 percent of the

[55]IPCC, *IPCC Special Report on Carbon Dioxide Capture and Storage.*

[56]IPCC, *IPCC Special Report on Carbon Dioxide Capture and Storage* (2005); National Academy of Sciences, *Prospective Evaluation;* and Congressional Research Service, *Community Acceptance of Carbon Capture and Sequestration Infrastructure: Siting Challenges* (July 2008).

respondents were familiar with the terms carbon dioxide capture and storage or carbon storage.

Some of the stakeholders we interviewed explained that public opposition could indeed grow when CCS extends beyond the relatively small projects used to enhance oil and gas recovery, to include much larger CO_2 sequestration projects located in more populated areas. One noted, in particular, that a lack of education about CCS's safety could potentially create confusion and fear when commercial-scale CCS is implemented.

Citing such concerns, a recent report by the National Academy of Sciences underscored the importance of public outreach, noting that while the success of DOE's carbon capture program depends heavily on its ability to reduce the cost of the technology, "the storage program cannot be successful if a significant fraction of the public views it as dangerous or unacceptable. Thus, the technologies must not only be safe and effective, they must be explainable to the public and the regulatory community in such a way as to instill confidence that they are in fact safe and effective."[57] The report went on to caution that "the federal government in general and the DOE in particular have not had a good track record in accomplishing this task in other programs." For its part, EPA received similar advice from its Clean Air Act Advisory Committee's Advanced Coal Technology Work Group. The Work Group's January 2008 report recommended that the agency immediately develop, in consultation with other agencies, a public outreach effort to explain carbon capture and sequestration.[58] A diverse group of panel members at EPA's 2007 UIC workshop made similar recommendations for public outreach and participation.

Accounting System for Measuring CO_2 Stored by CCS for Use in a CO_2 Emissions Trading Plan

According to a recent federal advisory committee report, an accounting system, or protocol, will be needed to quantify the CO_2 emissions from CCS. The accounting protocol could clarify uncertainty related to monitoring, reporting, quality assurance and control, and cross-border issues. Establishing this protocol would be a necessary step to integrate projects that prevent CO_2 from being emitted to the atmosphere into a future regulatory regime that addresses climate change. The advisory committee report also notes that the IPCC has released national

[57]National Academy of Sciences, *Prospective Evaluation*.

[58]Clean Air Act Advisory Committee Advanced Coal Technology Work Group, Final Report of the Advanced Coal Technology Work Group.

greenhouse gas inventory guidelines for CO_2 capture, transport, injection, and storage, and that a comprehensive CCS accounting protocol developed by EPA and other agencies would provide needed guidance for applying IPCC Guidelines in the United States.

The European Union's experience suggests that in planning for future CCS deployment, it is important to address such practical issues early in the process, particularly how to address reductions in emitted CO_2 achieved by CCS. Specifically, the European Commission proposes to revise the EU ETS to include CO_2 capture facilities, pipelines, and storage sites. A European Commission report acknowledges that resolution of this important practical matter is important to remove barriers to future CCS deployment.[59] Although EU member states can seek to include CCS projects in their national emissions cap by gaining approval from the European Commission on a case-by-case basis, proposed legislation would explicitly include, after 2012, facilities involved in the capture, transportation, and storage of CO_2 in the ETS. These facilities would then earn allowances for nonemitted CO_2 and would have to surrender emission allowances for any leakages of CO_2 that occur.

Thus far, EPA's Office of Air and Radiation has begun to develop a rule requiring mandatory reporting of greenhouse gas emissions from all sectors of the economy.[60] The agency is not, however, developing a protocol clarifying how emissions avoided as a result of a CCS project would be measured, nor how a future emissions trading plan would treat the avoided emissions. EPA officials explained that, given the pressure of other priorities, they would only develop such a protocol when mandated by Congress to do so. However, they noted that such an accounting system would be closely linked to the design of voluntary programs, future policies, and regulations to reduce greenhouse gas emissions.

[59]EU Commission Staff Working Document, accompanying document to the *Proposal for a Directive of the European Parliament and of the Council on the Geologic Storage of Carbon Dioxide*, January 23, 2008.

[60]Specifically, EPA officials told us they are developing a proposal that would require "upstream" producers and "downstream" sources above appropriate thresholds to report their greenhouse gas emissions.

Conclusions

Recent federal and international assessments indicate that the United States will need to rely on CCS as an essential mitigation option to achieve appreciable reductions in greenhouse gas emissions. Federal agencies whose action—or inaction—will greatly affect the prospects for timely CCS deployment have taken early steps that address some barriers to CCS, but have left critical gaps that impede our understanding of CCS's full potential for reducing CO_2 emissions and that could affect CCS deployment on a broader scale.

DOE has invested heavily in advancing CCS in IGCC plants, but knowledgeable authorities agree that these facilities will account for only a small percentage of power plants' CO_2 emissions in the next several decades to come. DOE has recently begun to shift its approach in a way that also emphasizes development of CCS technology for existing coal-fired power plants. Given the broad consensus that the technology used by these plants will dominate coal-fired power plant capacity for the next several decades—both in the United States and around the world—we believe the agency should continue this trend. EPA has begun to address some of the regulatory uncertainties under the SDWA that will need resolution for a national CCS program to move forward, but other key issues associated with other environmental statutes—such as RCRA, CERCLA, and the NSR provisions of the Clean Air Act—have not been addressed.

In addition to these key barriers, there is an array of other issues that would need to be resolved if the technology is to be deployed within a time frame scientists believe is needed to address climate change. Moreover, whereas many of the technical and regulatory issues discussed earlier fall within the domain of two key agencies (DOE and EPA), these other issues cross the jurisdictions of the Departments of the Interior and Transportation, FERC, and other agencies in a manner that would require collaboration between agencies and, in many cases, coordination with state governments and other entities. While the DOE-led CCTP coordinates climate change technology research, development, demonstration, and deployment among federal agencies, it has not been tasked with resolving the issues of CO_2 pipeline regulation and infrastructure and liability for stored CO_2, among other issues. Furthermore, officials from relevant offices within the Departments of the Interior and Transportation told us they have not yet been invited to participate in CCTP discussions.

Recommendations for Executive Action

We recommend that the Secretary of Energy direct the Office of Fossil Energy to continue its recent budgetary practice of helping to ensure that greater emphasis is placed on supporting technologies that can reduce greenhouse gas emissions at existing coal-fired power plants.

We recommend that the Administrator of EPA more comprehensively examine barriers to CCS development by identifying key issues that fall outside the agency's SDWA authority. Specifically, we recommend that the Administrator direct the cognizant EPA offices to collectively examine their authorities and responsibilities under RCRA, CERCLA, and the Clean Air Act for the purposes of (1) obtaining the information necessary to make informed decisions about the regulation of (and potential liabilities associated with) the capture, injection, and storage of CO_2; (2) using this information to develop a comprehensive regulatory framework for capture, injection, and underground storage of CO_2; and (3) identifying any areas where additional statutory authority might be needed to address key regulatory and legal issues related to CO_2 capture, injection, and storage.

We recommend that the Executive Office of the President establish an interagency task force (or other mechanism as deemed appropriate) to examine the broad range of issues that, if not addressed proactively, could impede large-scale commercial CCS deployment and to develop a strategy for cognizant federal agencies to address these issues. Among the issues this task force should examine are: (1) identifying strategies for addressing regulatory and legal uncertainty that could impede the use of federal lands for the injection, storage, and transport of CO_2; (2) examining how any regulation of carbon emissions will address leakage of stored CO_2 into the atmosphere; (3) developing an accounting protocol to quantify the CO_2 emissions from capture, transport, injection, and storage of CO_2 in geologic formations; (4) examining CO_2 pipeline infrastructure issues in the context of developing a large-scale national CCS program; (5) developing a public outreach effort to explain CCS; (6) evaluating the efficacy of existing federal financial incentives authorized by the Energy Policy Act of 2005 and other relevant laws in furthering the deployment of CCS; and (7) examining the federal and state resources required to implement the EPA's expanded UIC program incorporating commercial-scale CCS.

Agency Comments and Our Evaluation

We provided a draft of this report to the Secretary of DOE and the EPA Administrator for review and comment. DOE's September 9, 2008, letter first "commend[s]… the comprehensiveness of this study, including the analysis of potential barriers to widespread commercialization of CCS and

the potential need for involvement by multiple Federal agencies." The letter's subsequent comments are also consistent with the report's recommendations that (1) DOE continue to place greater emphasis on pursuing increased funding for CO_2 emissions control technologies for existing coal-fired power plants and (2) an interagency task force be established to examine critical CCS issues and develop a comprehensive CCS strategy. However, the agency expressed disagreement with our rationale for placing greater emphasis on CCS technologies applicable to these facilities and suggests a different approach for the interagency task force we recommended:

- *Placing greater emphasis on existing coal-fired power plants*. DOE says that while it agrees with the report's findings concerning the importance of pursuing CCS options for existing coal-fired power plants, these findings incorrectly imply "that DOE has focused too heavily on the IGCC option for new plants at the expense of retrofit opportunities." We are not second-guessing decisions DOE made in past decades. Rather, we are concerned about how the agency can best move forward in light of the new emphasis on substantially reducing CO_2 emissions and the scientific consensus that CCS will be needed to help reduce emissions.

- *Establishing an interagency CCS Task Force*. DOE maintained that a coordinating body—the DOE-led CCTP—already addresses these kinds of issues. However, the CCTP's scope focuses on technology; it does not address legal and institutional issues such as the resolution of CO_2 pipeline regulation and infrastructure or liability for stored CO_2, among others. In addition, officials from cognizant offices within the Departments of the Interior and Transportation told us they have not yet been invited to participate in CCTP discussions. Moreover, we continue to believe that a more centralized task force, with a broader scope than the technology-focused CCTP, may be a preferable alternative.

DOE's letter appears in appendix II, along with our responses to each of its main points. The agency separately provided technical comments, which were incorporated in our final report, as appropriate.

EPA's September 12, 2008, letter stated that providing regulatory certainty on issues related to geological storage of CO_2 was a high priority for the agency and agreed with the intent of our recommendation—to provide clarity on how the broader range of statutes within the agency's jurisdiction may apply. The agency noted that it had made an initial effort to identify and discuss these issues in the preamble of its July 2008 proposed rulemaking and had requested comments on many SDWA

topics—including some of those identified in our report. It said it expected further progress on these SDWA topics after receiving input from stakeholders during the comment period (which extends through November 24, 2008). EPA did not respond to the recommendation that an interagency task force be established to examine critical CCS issues and to develop a comprehensive CCS strategy. The agency also offered several other comments and clarifications, which are presented in appendix III, along with our responses.

We are sending copies of this report to the Administrator of EPA; the Secretary of Energy; the House Select Committee on Energy Independence and Global Warming; appropriate congressional committees; and other interested parties. We will also make copies available to others on request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202)512-3841 or stephensonj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions are listed in appendix IV.

Sincerely yours,

John B. Stephenson
Director, Natural Resources and Environment

Appendix I: Objectives, Scope, and Methodology

We were asked to examine (1) the key economic, legal, regulatory, and technological barriers impeding commercial-scale deployment of carbon capture and storage (CCS) technology and (2) the actions federal agencies are taking to overcome barriers to or facilitate the commercial-scale deployment of CCS technology.

To determine the key economic, legal, regulatory, and technological barriers impeding commercial-scale deployment of CCS, we reviewed assessments by the Intergovernmental Panel on Climate Change, the National Academy of Sciences, federal agencies, nongovernmental organizations, and academic researchers. We also contacted a nonprobability sample of stakeholders from industry, including officials from electric power companies and oil and gas companies, as well as stakeholders from nongovernmental organizations and academic researchers. We selected major U.S. energy producing companies, as well as organizations and researchers that participate actively in ongoing dialogues on CCS. We also selected a number of smaller companies and organizations to ensure that we obtained a broader range of perspectives on key issues.[1] We used a semistructured interview guide to interview these stakeholders and facilitate analysis of what stakeholders identified as key economic, legal, regulatory, and technological barriers impeding commercial-scale deployment of CCS. To obtain federal agency officials' perspectives on key economic, legal, regulatory, and technological barriers, we conducted interviews with officials from the Department of Energy's (DOE) Office of Fossil Energy, the Environmental Protection Agency's (EPA) Office of Ground Water and Drinking Water and Office of Air and Radiation, as well as other agencies, primarily in the Department of the Interior and Department of Transportation.

To examine the actions federal agencies are taking to overcome barriers to or facilitate the commercial-scale deployment of CCS technology, we conducted interviews with officials from the DOE's Office of Fossil Energy and the EPA's Office of Ground Water and Drinking Water and the Office of Air and Radiation to assess these agencies' efforts to overcome barriers to or facilitate the commercial-scale deployment of CCS. Moreover, we reviewed a report by the National Academy of Sciences assessing DOE's Fossil Energy research and development programs. We reviewed reports

[1]Results from nonprobability samples cannot be used to make inferences about a population. This is because, in a nonprobability sample, some elements of the population being studied have no chance or an unknown chance of being selected as part of the sample.

made by two federal advisory committees, the National Coal Council advising the Secretary of Energy and the Clean Air Act Advisory Committee advising the EPA Administrator, and asked agency officials how they were implementing recommendations contained in these reports. We obtained and analyzed 12 years of DOE budget information, from fiscal year 1997 through the present, to assess the funding DOE has provided for various CO_2 capture related technologies. We reviewed the proposed EPA rule for the underground injection of CO_2 for geologic sequestration under the Safe Drinking Water Act. To obtain perspectives from outside the government, using the methodology described above we contacted a nonprobability sample of stakeholders and used a semistructured interview guide to facilitate an aggregate analysis of stakeholders' assessments of the actions of federal agencies. To assess the extent to which other federal agencies are overcoming barriers to or facilitating the commercial-scale deployment of CCS technology, we also conducted interviews with officials from federal agencies in the Department of the Interior and Department of Transportation (DOT), including the U.S. Geological Survey, Bureau of Land Management, Surface Transportation Board, and DOT's Pipeline and Hazardous Materials Safety Administration, as well as the Federal Energy Regulatory Commission. To assess the role of the Climate Change Technology Program (CCTP) in coordinating CCS-related activities across federal agencies, we interviewed a senior CCTP official and asked officials at several federal agencies about their involvement in CCTP activities. Finally, we attended two stakeholder workshops the EPA held concerning development of proposed regulations for the underground injection of CO_2 for geologic sequestration under the Safe Drinking Water Act.

We conducted this performance audit from October 2007 to September 2008 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Comments from the Department of Energy

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

Department of Energy
Washington, DC 20585
September 9, 2008

Mr. John B. Stephenson, Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, NW, Room 2T47
Washington, D.C. 20548

Dear Mr. Stephenson:

Thank you for the opportunity to review and submit comments on the GAO draft report: **Federal Actions Will Greatly Affect the Viability of Carbon Capture and Storage As a Key Mitigation Option** (GAO-08-1080).

We commend GAO for the comprehensiveness of this study, including the analysis of potential barriers to widespread commercialization of CCS and the potential need for involvement by multiple Federal agencies.

See comment 1.

Regarding GAO findings related to DOE's CCS research, development and demonstration (RD&D) activities, we agree with the report's finding concerning the importance of pursuing CCS options for the sizeable existing coal power plant fleet. However, we do not believe that GAO has correctly assessed the significance and priority of other major components of DOE's CCS programs, such as the integrated gasification combined cycle (IGCC) technology. The report states that most coal-related emissions will come from existing plants "for many years to come." It further notes that funding for the IGCC Program has been much greater than that for RD&D applicable to existing pulverized coal power plants, the implication being that DOE has focused too heavily on the IGCC option for new plants at the expense of retrofit opportunities. That is not correct.

See comment 2.

Emissions from existing plants are important, but emissions for new plants that could be in service for 50 years cannot be ignored, and current trends indicate that globally many new coal power plants will continue to be built in coming decades. Of the various options for combining new coal power plants with CCS, systems analysis suggests that advanced IGCC subsystems being developed in the DOE program can lead to a dramatic reduction in the overall costs of CCS systems. With the addition of lower-cost approaches under development for capturing CO_2 in IGCC plants, IGCC/CCS systems have the potential to be the lowest-cost CCS option for coal power plants. The goal is to drive CCS cost sufficiently low to encourage large developing countries such as China and India to eventually deploy CCS as they continue to build their economic expansion on their large, domestic coal resource bases. If these countries do not adopt CCS in a timely manner, it may not be possible to reduce greenhouse gas emissions sufficiently to limit atmospheric concentrations of GHGs to acceptable levels.

See comment 3.

See comment 4.

See comment 5.

The GAO report supports increased funding for CCS retrofit applications, including DOE's recent increased funding requests. These funding requests, however, are not the result of recent changes in DOE's CCS priorities (which should be sustained), as suggested by the report. Although DOE funding for CO_2 CCS was relatively modest as recently as FY 2000, significant work has been underway for much of DOE's CCS program history on CO_2 capture technologies, including retrofit applications. These technologies were in their infancy when work first started, and it is important to thoroughly investigate such technologies at smaller scale for an extended period before it can be determined if larger-scale testing is justified. As a result, capture funding has been relatively modest, but is expected to increase as promising options are ready to be scaled up.

The GAO report also raises the question of priorities based on significantly higher current DOE funding for CO_2 storage versus capture activities. This funding difference again reflects where different activities are in the RD&D funding pipeline. CO_2 storage technology is built on decades of petroleum industry experience, and this has allowed work in this area to progress rapidly to field testing. Field testing is expensive, particularly due to the cost of CO_2, and thus storage activities currently account for a relatively large share of the Sequestration Program budget.

Finally, regarding the GAO recommendation that an interagency task force be established to develop a strategy addressing CCS commercialization barriers, addressing such barriers is already an important focus of the existing interagency U.S. Climate Change Technology Program. This program led by DOE, has an experienced staff, resources, and includes representation from relevant Federal agencies. CCTP was authorized by the Energy Policy Act of 2005, Title XVI, and directed to develop such strategies, and work is underway. The recommended strategy could be carried out under this Program without the organizational and delay issues that would likely occur if a new group were constituted to address the complex task being proposed.

Additional general and detailed comments are attached. If you have any questions, you may direct them to Kevin Clark, Audit Liaison, 301-903-4293.

Sincerely,

James A. Slutz
Assistant Secretary (~~Acting~~)
Office of Fossil Energy

The following are GAO's comments on the Department of Energy's letter dated September 9, 2008.

GAO Comments

1. DOE says that while it agrees with the report's findings concerning the importance of pursuing CCS options for existing coal-fired power plants, these findings incorrectly imply "that DOE has focused too heavily on the IGCC option for new plants at the expense of retrofit opportunities." We are not second-guessing decisions DOE made in the decades before concerns about carbon dioxide (CO_2) emissions had taken on the prominence they have today. Rather, we are concerned about how the agency can best move forward in light of the new emphasis on CO_2 emissions and the scientific consensus that CCS will be needed to help deal with them.

2. DOE says that even though CO_2 emissions from existing plants are important, current global trends indicate that many new coal power plants will continue to be built in coming decades and that many would choose IGCC as the lowest-cost CCS option if it were available. However, a DOE report, *Tracking New Coal-Fired Power Plants*, indicates that the new coal fired power plants currently being built and permitted in the United States are predominately using pulverized coal technologies, with a smaller number of plant operators opting for IGCC technology. Furthermore, DOE cites the importance of controlling CCS emissions in developing countries—in particular, China and India. However, the International Energy Agency states that "the expansion of coal-fired generation in China will continue to be based on pulverized coal" and observes that all of India's operating coal-fired power plants use a form of pulverized coal technology. That said, our report does not call for a radical shift in focus from IGCC to conventional technology, but rather a budgetary strategy that appropriately reflects a greater emphasis on developing capture technologies that could be applied to existing pulverized coal power plants. As our draft report noted, such a strategy has in fact already been reflected in recent DOE budgets.

3. DOE acknowledges that it has recently increased requested funding for CCS technologies applicable to existing plants, but states that the increase does not necessarily reflect a higher priority. Rather, the increase reflects an evolution of the technology development process. Specifically, it is now moving from investigating such technologies from a less costly small scale to the point where costs rise as technology development is "scaled up." Recent statements by the agency, however, suggest that research applicable to existing coal-

fired power plant technologies do warrant a higher priority. In particular, DOE's recent funding announcement for CCS technology development for existing pulverized coal power plants states that this funding opportunity is "driven by the fact that existing coal-fired power plants produce a sizeable portion of current CO_2 emissions from all fossil fuel-based sources, and that only about 6 GW of the existing coal-fired electricity generating fleet is projected to retire by 2030." Similarly, in our discussions with DOE fossil energy officials about their fiscal year 2008 budget priorities, they pointed to language in House Report 110-185, which recommended "a rigorous research program on the potential for retrofitting existing coal plants for CO_2 capture and sequestration."

4. DOE questions the report's observation that funding for CO_2 storage has been significantly higher than the resources devoted to CO_2 capture, noting that the higher funding level for storage-related activities reflects the fact that it has evolved to the point where advances in storage would now require expensive field-testing. We do not dispute the need to invest in the field-testing of storage activities. Rather, we note that timely CCS deployment will occur only if progress is made with both capture and storage and that considerably more progress is needed on the capture front. A comprehensive CO_2 storage capability will mean little if there is no CO_2 to store.

5. DOE maintains that a coordinating body—the DOE-led Climate Change Technology Program (CCTP)—already addresses CCS-related issues. However, the CCTP's scope focuses on technology; it does not address legal and institutional issues such as CO_2 pipeline regulation and infrastructure or liability for stored CO_2, among others. In addition, officials from cognizant offices within the Departments of the Interior and Transportation told us they have not yet been invited to participate in CCTP discussions. Moreover, we continue to believe that a more centralized task force, with a broader mission than the technology-focused CCTP, may be a preferable alternative.

Appendix III: Comments from the Environmental Protection Agency

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

SEP 12 2008

OFFICE OF WATER

John B. Stephenson
Director, Natural Resources and the Environment
Government Accountability Office
Washington, DC 20548

Dear Mr. Stephenson:

Thank you for the opportunity to review the draft Government Accountability Office (GAO) Report: ***Federal Actions Will Greatly Affect the Viability of Carbon Capture and Storage as a Key Mitigation Option (GAO-08-1080),*** dated September 2008. The Environmental Protection Agency (EPA) coordinated with your Office throughout the study and provided additional material at your request, and our professional staff was made available for a number of meetings. I want to compliment the professional manner in which your staff conducted the study. We appreciate their positive responses to the comments we provided on earlier drafts.

Our three major areas of concern are related to authorities under the Safe Drinking Water Act (SDWA); the discussion of the interplay with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA); and several key issues related to Geologic Sequestration (GS) but outside the authority of the SDWA. We will provide you the primary concerns within this letter and hope that these can be addressed in the final version of your GAO report.

EPA recognizes the importance of Carbon Capture and Storage (CCS) in contributing to CO_2 emissions reductions and is committed to working with both governmental and external partners to facilitate deployment of this technology in a safe and reliable manner. For over twenty-five years, the Underground Injection Control (UIC) program has successfully protected our nation's drinking water resources by regulating the underground injection of fluids and will continue to do so for the unique case of GS.

EPA comments on discussion of SDWA-related issues

See comment 1.

Early in the report, GAO suggests that EPA "more comprehensively examine barriers to CCS development under the Safe Drinking Water Act." EPA believes that the recently proposed UIC GS rule (July 15, 2008) fully covers SDWA-related issues. EPA,

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working with partners at the Department of Energy (DOE) and several State regulatory agencies, proposed these new UIC regulations specifically for commercial-scale GS. The public comment period is currently ongoing for this proposed regulation and promulgation of the rule is anticipated in late 2010 or early 2011. The GAO report includes a preliminary discussion of the recently proposed UIC rule. We suggest that information related to this proposed rule should be placed as early in the report as possible. Although there may be misunderstandings among certain stakeholders regarding the regulatory framework for CO_2 injection, EPA has been clear that there is no regulatory impediment to seeking a permit for large-volume injection of CO_2 under the existing UIC program. In fact, depending on the nature of the injection activity, CO_2 injection could currently be permitted as a Class I, Class II or Class V UIC well. The purpose of the Class VI well category which is proposed in EPA's rule is to provide a more appropriate well classification for program implementation of this technology on a large scale.

The draft report mentions 'ambiguity' regarding whether the operator of a GS site will remain liable indefinitely for potential problems posed by leakage of CO_2. EPA has been clear during discussions with stakeholders that, consistent with current UIC regulations under the SDWA applying to all injection wells, the owner/operator of a GS site will be held liable indefinitely for potential damages caused by leakage of CO_2. Some stakeholders may feel confused about this issue; GAO's report, however, should represent EPA's position, which is also reflected in the proposed rule.

See comment 2.

In addition, the report discusses government indemnification of the potential liability associated with GS sites. It is important to note that EPA does not have authority under the SDWA to release or indemnify injection well owners/operators from long-term liability. Thus, the report should clarify that it is currently beyond the Agency's authority to do this.

See comment 3.

Finally, EPA has stated in the proposed Class VI regulation that owners and operators of GS sites must demonstrate financial responsibility for the operation and post-injection site care phases of the project. However, EPA acknowledges the need for additional information and plans to provide guidance on how additional financial responsibility can be demonstrated.

EPA comments on GAO discussion of CERCLA and RCRA

The GAO report states that ambiguity exists regarding how CERCLA and RCRA regulations may apply to GS sites and states that the proposed EPA UIC-GS rule does not resolve, does not address and is 'unclear' regarding these issues. EPA would appreciate if, at the beginning of this discussion, GAO would note that EPA has discussed RCRA and CERCLA issues in the preamble to the proposed regulation. EPA is currently in the process of further evaluating how CERCLA and RCRA may apply to GS sites. However EPA's proposed rule is clear that if a CO_2 stream meets the definition of "hazardous waste" it may only be injected under the existing provisions for a Class I hazardous well, which by definition is subject to RCRA, and if it falls within certain

See comment 4.

See comment 5.

See comment 6.

categories of hazardous waste, it may not be injected unless EPA grants a RCRA exemption. Such hazardous waste streams would not be subject to the proposed Class VI permit. Finally releases of a hazardous substance beyond the scope of a federally-permitted release may be subject to CERCLA authorities.

EPA comments on GAO discussion of issues outside of SDWA authorities

The UIC proposed regulations include clarifications on the effect of permits on property rights. 40 CFR 144.35 (b) and (c) clearly state that the issuance of a permit does not convey any property rights of any sort, or any exclusive privilege, and the permit does not authorize any injury to the persons or property or invasion of other private rights, or any infringement of State or local law or regulations. While EPA's proposed rule includes a discussion of how regulations may impact these issues, EPA does not have the authority to propose federal regulations related to property rights. To be clear, EPA does not anticipate resolving issues outside the scope of the SDWA in the context of the regulatory action recently proposed under the UIC program.

EPA response to specific GAO recommendation

GAO recommends that EPA offices "collectively examine their authorities and responsibilities under RCRA, CERCLA, and the Clean Air Act…" Providing regulatory certainty on issues related to GS is a high priority for the Agency and EPA agrees that it is important to provide clarity on the various statutes that may apply. EPA made an initial effort to identify and discuss issues related to SDWA, RCRA and CERCLA in the preamble of its July 2008 proposal and specifically requested comments on various topics including some of those identified by GAO. We hope that the input we receive through the public comment process, in combination with our own efforts to work across EPA to assess implications of these various statutes on GS, will shed more light on these important issues.

We have a few additional comments on the draft final report which we are providing as an enclosure to this letter. Again, we appreciated the opportunity to coordinate with your staff on this project. Should you need additional information or have further questions, please let me know. You may also contact Cynthia C. Dougherty, Director of the Office of Ground Water and Drinking Water, at (202) 564-3750.

Sincerely,

Benjamin H. Grumbles
Assistant Administrator

Enclosure

The following are GAO's comments on the Environmental Protection Agency's letter dated September 12, 2008.

GAO Comments

1. EPA says that its recently-proposed UIC rule fully covers Safe Drinking Water Act (SDWA)-related issues. We have modified the report to more fully reflect the work that EPA is doing to examine SDWA-related barriers to CCS deployment. However, while we acknowledge that the proposed rule discusses and seeks comments on many issues, we continue to believe that it leaves many of these issues unresolved. While EPA's proposed rule prohibits the injection of CO_2 above the lowermost formation containing an underground source of drinking water, EPA is still exploring whether the UIC director should be given the authority to approve such an injection—an issue that can affect whether unmineable coal seams are used for CO_2 storage.

2. EPA suggests that the report should state EPA's position on whether the operator of an injection well will remain liable indefinitely for potential problems posed by leakage of CO_2. Pages 23 and 39 of the draft report did in fact state that well operators remain responsible indefinitely for any endangerment for underground sources of drinking water caused by such leakage. However, the draft report also addressed other unresolved liability issues of concern to stakeholders, which are unrelated to endangerment of underground sources of drinking water. We have added language to further emphasize these issues.

3. EPA says that it is important to note that the agency does not have authority under the SDWA to release injection well owners or operators from long-term liability. The draft report had already done so on page 39 and 40, where it explained that EPA does not have the statutory authority to release well owners or operators from liability or transfer financial responsibility from the well owner or operator to a third party. In response to EPA's comments, we have added language to the report to further clarify this point.

4. EPA suggests that GAO note in its final report that EPA had discussed RCRA and CERCLA issues in the preamble to its proposed rule. The draft report had, in fact, mentioned that EPA addressed RCRA and CERCLA issues in the preamble. For example, page 42 of the draft noted that the preamble explained that pure CO_2 in and of itself is not listed as a hazardous substance under CERCLA, and cautioned that injected CO_2 streams could contain hazardous constituents that would make these streams "hazardous." That said, we continue to believe that

the preamble's limited treatment of these issues still leaves much to be resolved about the implications of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) for CO_2 sequestration. Specifically, EPA suggests that determinations about whether injected CO_2 is a hazardous waste or substance will be made on a case-by-case basis. Moreover, EPA says it is "currently in the process of further evaluating how CERCLA and RCRA may apply to [geologic sequestration] sites."

5. EPA notes that the proposed rule includes clarifications on the effect of permits on property rights. However, these effects were not among the property rights-related issues of greatest concern to the stakeholders we interviewed. As we stated in the report, these stakeholders told us they were concerned about a lack of clarity regarding ownership of injected CO_2 and ownership of geologic formations.

6. Notwithstanding the permit-related property rights issues raised in comment 5 above, EPA explains that it does not have the authority to propose federal regulations related more broadly to property rights issues. We agree that EPA's authority does not extend to many of these issues discussed in the report, which is why the report notes that the resolution of this and other issues will require the involvement of other federal agencies and, in some cases, states.

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

John B. Stephenson, (202) 512-3841 or stephensonj@gao.gov

Staff Acknowledgments

In addition to the contact named above, Steve Elstein, Assistant Director; Chuck Bausell; Cindy Gilbert; Katheryn Summers Hubbell; Michael O'Neill; Ben Shouse; Jeanette Soares; and Michelle Woods made major contributions to this report. Additional assistance was provided by Katherine M. Raheb and Melinda Cordero.

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