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CARBON CAPTURE AND SEQUESTRATION No. 1

Opportunities and Challenges for Carbon Capture and Sequestration

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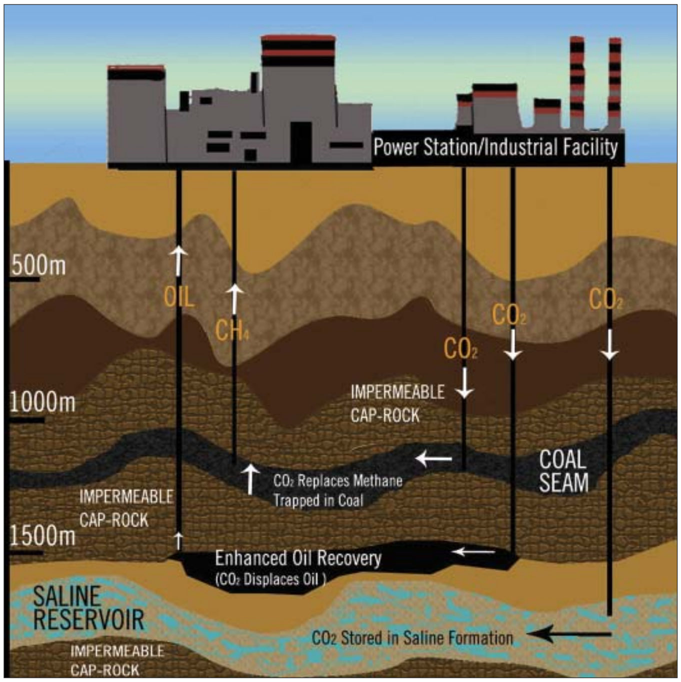

Summary

Carbon capture and sequestration (CCS) could become an important option to limit carbon dioxide emissions that are now causing global climate change. Interest in CCS has grown in North America, Europe, and Asia over the past 5 years. Selected challenges facing the technology include: developing a policy driver to incentivize deployment; defining a flexible and adaptable regulatory framework; and funding large-scale demonstration projects to resolve technical and integration uncertainties as well as reduce high costs. Addressing these three challenges will help solve a fourth: public acceptability. Debate over the timing of CCS deployment is likely to continue, but it is clear that this climate mitigation option is critical to eventual stabilization of greenhouse gas concentrations in the atmosphere.

This policy brief outlines high-level issues related to deployment of carbon dioxide capture and geological sequestration (CCS). It serves as a broad introduction to some of the key challenges that must be addressed for wide-scale deployment of CCS. Forthcoming papers in this WRI series will address selected issues in greater depth.

CCS is one option for reducing anthropogenic greenhouse gas emissions that are now altering the global climate system. The CCS process starts with capturing carbon dioxide from power plants or other large industrial point sources, transporting it to suitable locations, and injecting it into underground reservoirs. Interest in CCS has grown in recent years as it would significantly reduce emissions from fossil fuels, which are expected to continue to meet the world's energy needs for decades to come due to their widespread availability and low cost. Challenging economic, technical, social, and institutional hurdles remain, however, before CCS can contribute significantly to a larger climate solution.

Potential for Reducing CO_2 Emissions

The global community must reduce greenhouse gas emissions significantly and quickly to prevent catastrophic climate change. According to the latest UN Intergovernmental Panel on Climate Change (IPCC) report, even to hold global mean temperature increases to 2.6°C (4.7°F) or less, global emissions should peak and then begin declining by 2020 (IPCC, 2007). Even then, more frequent heat waves, droughts, severe storms, sea level rise, and other significant climate change impacts are expected.

Currently, fossil fuels meet about 80 percent of global energy needs, and demand for energy will increase as populations and incomes rise. While surveys have indicated that the general public supports renewable energy and energy efficiency as priority GHG mitigation options (Curry et al., 2007), their economic potential to cut emissions over the mid-term is likely insufficient to prevent the more serious impacts of climate change. Many experts believe that every climate mitigation option, including CCS, must be employed to stabilize atmospheric concentrations at a viable level (Socolow, 2004). Figure 1 offers one illustration

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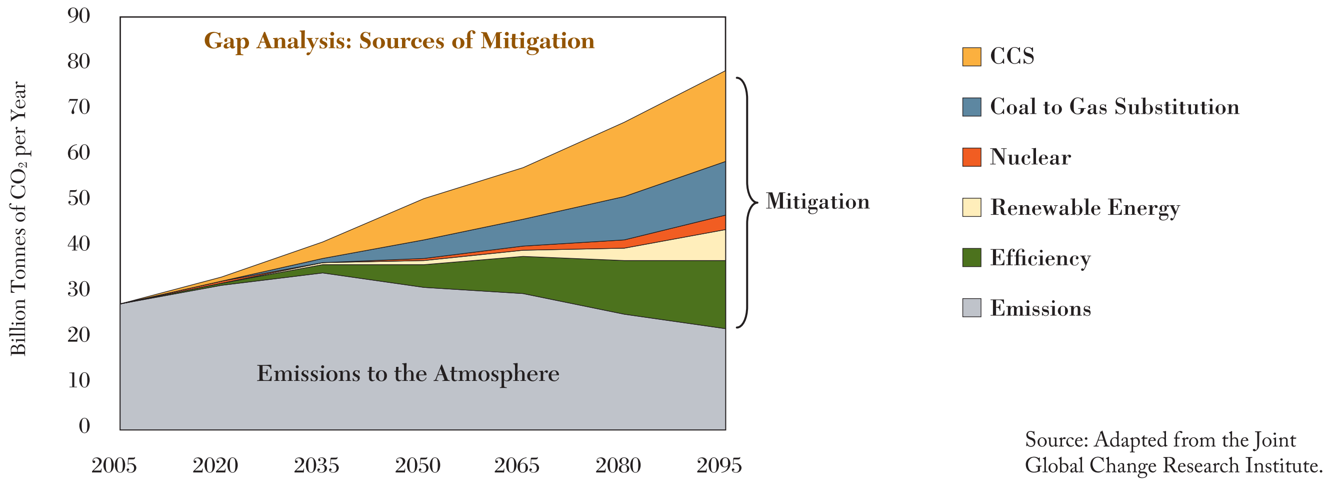
FIGURE 1 MiniCAM analysis of CO_2 reductions to reach 550 ppmv (parts per million by volume)



Source: Adapted from the Joint Global Change Research Institute.

of an economically efficient mix of CO_2 mitigation measures to stabilize atmospheric concentrations of carbon dioxide at 550 parts per million. Achieving lower concentration levels would likely demand still greater CCS deployment.

Elements of CCS

CCS is typically viewed as a three-step process: capture, transport, and sequestration. Capture is currently the most expensive step and the target of vital technology research focusing on cost reduction. Transporting CO_2 by pipeline, truck, or ship is a well-understood and established practice. Millions of tons, mostly from naturally occurring formations, are moved each year by the oil and gas industry for enhanced oil recovery (EOR). However, important issues regarding institutional coordination and regulation as a greenhouse gas mitigation strategy remain. Sequestration involves injecting CO_2 into deep underground formations.[1] Additional scientific understanding and practical experience is needed to define best practices and standards for large-scale sequestration.

Capture

Carbon dioxide capture requires separating CO_2 from industrial and energy-related process emissions into relatively pure streams and pressurizing it for transport. Only large point sources of CO_2 emissions such as power plants, steel mills, cement plants, refineries, ammonia and fertilizer plants, and coal-to-liquid plants are currently targeted as candidates for CCS. These sources account for over one-third of global CO_2 emissions, which are forecasted to increase substantially absent intervention.

There are currently four approaches for capturing CO_2. Post-combustion capture involves separation of the CO_2 from the flue gas, and is currently the technology of choice for most small-scale, commercial carbon capture applications. CO_2 can also be separated and captured from fuel before burning in pre-combustion decarbonization. Integrated gasification combined-cycle (IGCC) power plants use this approach. Oxy-fuel combustion is a third, emerging option to achieve a relatively pure stream of pressurized CO_2. This process uses oxygen instead of air for combustion, and produces a concentrated CO_2 exhaust stream. Last, CO_2 can be captured in limited quantities from industrial practices that do not involve fuel combustion, such as natural gas purification.

While many proven capture technologies exist, technological innovations that reduce the cost of capture as well as policy drivers that encourage deployment will determine which of these approaches will be more widely used. Different fuel characteristics and operating environments will also have an impact. Post-combustion capture is now the most mature option, although it is expensive and energy-intensive. Pre-combustion capture (IGCC) is estimated to have the lowest overall costs, although there are only two IGCC plants in operation in the U.S. and more deployment experience is needed (MIT, 2007). Finally, oxyfuel combustion is still in the demonstration phase, and more testing—particularly at larger scales—is

1. Most sequestration projects will inject at depths of 800 meters or more.

needed. Advances in separating oxygen from air could someday make this option very attractive.

Reducing costs will be the most important objective in the near-term, but other uncertainties must also be resolved. Viable capture technologies will almost certainly be needed for both new plants and for retrofit of existing plants.[2] Requirements that new plants be "capture ready"— designed with additional room to install capture technology at a later date—may guide utility investment decisions with greater certainty. However, trade-offs in operating efficiency and system integration call for careful consideration. Defining purity requirements for the compressed stream of carbon dioxide also requires more trade-off analysis. Lower purity standards can cut costs substantially, but may introduce other technical, environmental, and social problems.

Transport

After capture, CO_2 is delivered from the point source to the sequestration site. Dedicated CO_2 pipelines are the most efficient transport mode for shipment, but tanker trucks and ships can also be used. There are over 5,800 kilometers of pipelines dedicated to CO_2 transport in the U.S., mainly for use in enhanced oil recovery projects (CRS, 2007). Transport technology and regulations are considered relatively mature, at least relative to capture and underground sequestration; economies of scale and creation of a centralized pipeline network could lower costs marginally, but major cost reductions are unlikely.

Many new pipelines will need to be built to deliver captured CO_2 to sequestration sites if CCS is to have a significant impact on emissions. Pipelines would probably be structured in regional networks spanning a few states, as opposed to more extensive networks. The extent of these systems will be controlled by the heterogeneity of underground storage capacity and cost of construction and operation of long pipelines. In the U.S., a variety of agencies will need to coordinate these developments. State oil and gas commissions, the Federal Energy Regulatory Commission, regional and state Environmental Protection Agencies, and the Departments of the Interior, Energy, and Transportation may all play a role in siting, approving, and maintaining new CO_2 pipelines. Environmental risk assessments, eminent domain, and regulatory tariff setting are important issues for these institutions to consider.

2. China installed about 200 gigawatts of new coal-fired power plants between 2004 and 2006, illustrating the need to find an acceptable solution to existing plants. These new plants alone emit roughly 1 billion tons of carbon dioxide each year.

Sequestration

Sequestration refers to the process of injecting CO_2 into deep reservoirs, such as depleted oil and gas fields, saline reservoirs, and unmineable coal seams. Various trapping mechanisms prevent the CO_2 from migrating to the surface. The primary trapping force is a layer of impermeable caprock overlying the sequestration site. Additional mechanisms include capillary trapping, dissolution of CO_2 in aquifer fluids, and eventual mineralization (Benson, 2002). The existence of naturally occurring oil and gas reservoirs proves that large volumes of fluids can be effectively trapped underground for millions of years. Careful characterization of potential storage sites is perhaps the single most important step to ensure that CCS projects can sequester CO_2 for geologic periods of time.

Estimates of geological sequestration capacity throughout the world range from two trillion tons of CO_2 (IPCC, 2005) to 11 trillion tons (Dooley et al., 2006), likely enough capacity to accommodate several decades or perhaps more than a century's worth of global emissions. Efficiently linking potential sequestration sites with sources of CO_2 will be challenging given the volume of carbon dioxide involved. Potential sites for sequestering CO_2 underlie a large portion of the U.S., Canada and Australia. Some nations, such as Japan and South Korea, have little sequestration capacity (Dooley et al, 2006).

While sequestration costs are significantly less than those associated with capture, there is considerably less understanding of and experience with long-term sequestration. Oil companies have extensive experience injecting CO_2 into depleted oil reservoirs, but little experience injecting into deeper saline reservoirs. The greatest challenge in sequestration is to identify the best sites in terms of safety, permanence, and cost. Considerable underground imaging and testing is required to verify the suitability of locations before injection begins. More research and experience with demonstration projects will help to clarify remaining uncertainties. Computational models that simulate CO_2 behavior underground are improving rapidly, but must become more transparent to command confidence.

Environmental and Safety Concerns

Most experts believe that properly conducted CCS projects have manageable and acceptable risk profiles. That said, there are important safety and public confidence-building issues that should form the basis of any CCS regulatory framework.

There are six categories of physical risk associated with CCS projects (de Figueiredo, 2007):

1. Potential groundwater contamination from direct CO_2 leakage into a source of drinking water, or by catalyzing other pollutants to contaminate the water.
2. Induced seismicity risk due to the large volume of CO_2 injected underground and the resulting pressure build-up.
3. Risk to human health from either operational problems or leakage of CO_2 to the surface, where it can act as an asphyxiant at high concentrations.
4. Climate risk associated with slow, chronic or sudden, large releases of CO_2 to the surface.
5. Property damage risks such as potential contamination of underground assets (such as natural gas) with CO_2 or displaced brines.
6. The final risk is that of general environmental degradation resulting from leakage to the surface, impacting soil, trees, and other vegetation.

> *"With appropriate site selection informed by available subsurface information, a monitoring program to detect problems, a regulatory system, and the appropriate use of remediation methods to stop or control CO_2 releases if they arise, the local health, safety and environment risks of geological storage would be comparable to risks of current activities such as natural gas storage, EOR, and deep underground disposal of acid gas."*
>
> — IPCC Special Report on CO_2 Capture and Storage, 2005

As stated here by the IPCC, experts believe these risks are manageable if projects are properly sited, operated, and monitored. In their Special Report on CO_2 Capture and Storage, the IPCC states that "For well-selected, designed and managed geological storage sites…the fraction [of CO_2] retained…is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years" (IPCC, 2005). Serious consideration and integration of such risks in the beginning stages of CCS deployment will help reduce the likelihood of occurrence.

Current Activities

Global interest in CCS has expanded dramatically over the past five years, due to its potential to significantly reduce emissions. Three large-scale commercial projects have been capturing and injecting CO_2 underground for a number of years. Each project has a research and monitoring component; no evidence of leakage has been detected to date. These projects include:

- *Sleipner* — Since 1996, the Norwegian state-owned oil company Statoil has been injecting CO_2 into an undersea saline formation off the coast of Norway. The project separates CO_2 from natural gas production—a requirement before shipping—and injects approximately 1 million tons of CO_2 annually. High carbon taxes in Norway help drive the economics of this project.
- *Weyburn* — This commercial project delivers over 1 million tons of CO_2 from North Dakota to Saskatchewan, Canada each year for use in enhanced oil recovery. The CO_2 is captured at a coal gasification plant in Beulah, ND and sent across the border using a 200 mile pipeline.
- *In Salah* — This project is led by a consortium of energy companies including BP, and injects CO_2 into a depleted gas reservoir in Algeria. As at Sleipner, the project removes CO_2 impurities from the produced natural gas and injects it into a nearby saline reservoir.

Interest in all aspects of CCS, from capture technology to long-term liability policy, has mushroomed in recent years. Five selected collaborative research efforts are described in the text box on page 5.

Key Challenges

Important challenges that must be addressed before CCS is considered a mature technology are described below.

Identify and Fund Key RD&D

While each element of the carbon capture and sequestration technology chain has been developed and largely proven, significant gaps still need to be addressed in integrated deployment of the entire system. The urgency of addressing the challenge of climate change does not allow us to follow the traditional and sequential research, development, and demonstration (RD&D) path, which would require perhaps as much as 30 years for CCS to become commercial.

Some CCS components, such as CO_2 transport and injection for EOR, have been used for decades, and their cost and performance are relatively well-understood. However, there is limited experience with projects that capture and inject CO_2 for the purpose of long-term sequestration at scale. Large-scale demonstration projects are needed to test and better understand the cost and performance of capture technologies and storage reservoirs and to demonstrate to the public that CCS is a safe and effective carbon mitigation option.

Increased government support for RD&D over a diverse range of large-scale demonstration projects should focus on reducing capture costs, achieving a better understanding of the behavior of injected CO_2 in deep saline reservoirs, advancing monitoring and verification technologies, and integrating the various

Selected CCS Programs and Partnerships

- **International Energy Agency Greenhouse Gas R&D Programme** — The IEA Carbon Capture and Sequestration program is an international collaboration that serves as a clearing-house of information to promote development of CCS.
http://www.ieagreen.org.uk/
- **Carbon Sequestration Leadership Forum (CSLF)** — The CSLF is an international initiative focused on development of cost-effective technologies for the separation and capture of CO_2 for its transport and long-term safe sequestration.
http://www.cslforum.org/
- **CO_2 Capture Project (CCP)** — An international project funded by 8 of the world's largest energy companies focused largely on reducing costs of the technology needed to capture and store carbon.
http://www.co2captureproject.org
- **Carbon Sequestration Regional Partnerships** — The U.S. Department of Energy supports this partnership program, which conducts pilot projects aimed at testing carbon sequestration options.
http://www.fe.doe.gov/programs/sequestration/partnerships/
- **CO_2CRC — The Cooperative Research Centre for Greenhouse Gas Technologies** (CO_2CRC) is an Australian effort focusing on the logistic, technical, financial, and environmental issues of storing CO_2.
http://www.co2crc.com.au/

components of the entire system. The $1 billion FutureGen project is one example of a public-private initiative to move CCS technology forward through a large-scale demonstration project.

Provide Incentives

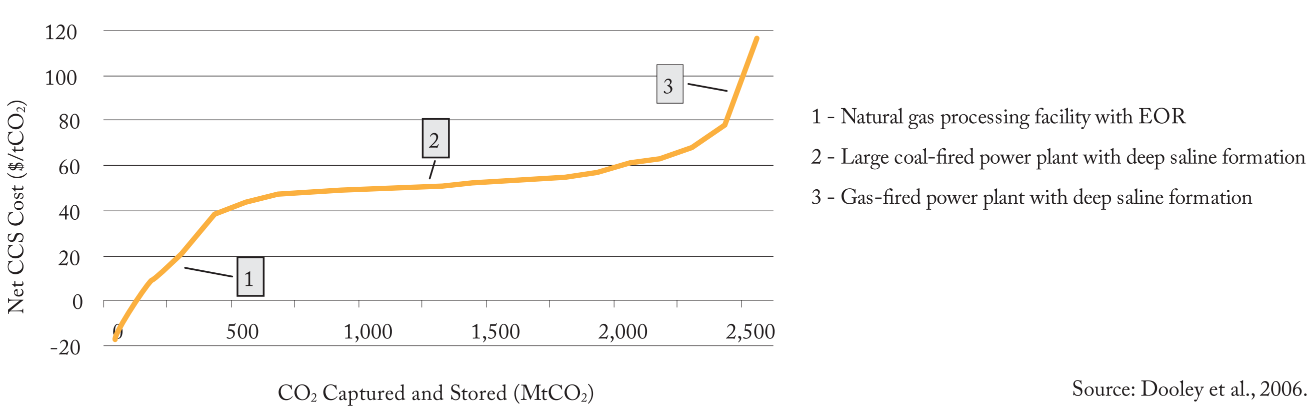
Costs associated with CCS vary widely depending on energy source, technology, location, and objectives. Natural gas processing plants that use captured CO_2 for EOR represent "low-hanging fruit," and this type of project may be economically feasible at just $10/ton CO_2; however, the sequestration potential is limited (see Figure 2). Today, a cost driver of about $40–60 per ton of carbon dioxide is required to make CCS economically feasible at a much larger scale at power plants. Power generators, project developers, and financiers will need economic or regulatory certainty before absorbing these costs. Currently the U.S. utility sector is reluctant to invest with certainty given the likely, although unknown nature of future carbon constraints.

Cap and trade is considered the most likely U.S. carbon mitigation regime in the near term. But initial price signals under such a regime are unlikely to reach the level needed to catalyze CCS projects. Special policies such as low-carbon portfolio standards or CO_2 performance standards will likely be needed to encourage the adoption of CCS (Sussman and Berlin, 2007).

Establish Regulatory Framework and Ensure Public Acceptability

There is currently no comprehensive regulatory framework in the U.S. designed to deal specifically with CCS. It seems likely that a variety of institutions, existing and new regulations, and industry-agreed best-practices will guide how initial projects

FIGURE 2 The Net Cost of Employing CCS within the U.S. - Current Sources and Technology



Source: Dooley et al., 2006.

are conducted. A recent authoritative study has called for the creation of a new public-private partnership in the U.S. with a specific mandate to manage a large-scale CCS demonstration program (MIT, 2007).

While little new regulation may be needed to oversee capture and transport components of CCS, sequestration will require new standards and increased cooperation between federal and state agencies. The current patchwork of regulations for both CO_2 transport and use will likely cause inefficiencies and increased costs if applied to wide-scale CCS practices. In addition, the existing standards were not designed with long-term carbon sequestration in mind. EPA's Underground Injection Control program governs the injection of CO_2 underground for EOR, and is widely considered adequate for that purpose. But the guidance set by this program does not address specific issues related to CCS, such as the larger volumes and higher pressures, measuring and monitoring, and long-term stewardship concerns.

Issues that a regulatory framework must address include: capture; transport; site characterization and permitting; operating standards, including monitoring, measurement, and verification and remediation plans; crediting of mitigated CO_2; and measures to deal with long-term stewardship.

Any regulatory framework must be able to adapt and evolve as our knowledge base grows, facilitating safe, yet efficient and cost-effective deployment.

Developing new regulations for CCS is integral to ensuring public acceptability. In the second WRI paper in this series, we will focus on how public acceptability for CCS and the regulatory framework are linked.

Summary

CCS will likely be a crucial bridging technology as we move to a low-carbon global economy, enabling us to meet our energy needs while reducing GHG emissions that contribute to climate change. A great deal of work is underway to develop and improve the technologies needed for wide-scale CCS deployment. However, much more is required to create a policy and regulatory framework that builds and instills public confidence in CCS.

In the next few years, deployment of large-scale commercial CCS projects will be essential to gain the experience necessary to reduce costs and improve efficiency. Ensuring that these projects meet the highest standards of safety will help win public acceptance of CCS and put the technology on the path toward achieving significant global emission reductions.

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This is the first in a series of WRI policy briefs on CO_2 capture and sequestration. It attempts to introduce many of the big-picture challenges related to wide-scale deployment of CCS as a carbon mitigation option. Other papers in this series will deal with more specific issues including public acceptability, liability, carbon accounting, and use of federal lands.

These briefs are part of a larger project WRI is leading with diverse stakeholders to create guidelines for CCS deployment. More information on this project is available at http://carboncapture.wri.org.

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