Capturing King Coal

Deploying Carbon Capture and Storage Systems in the U.S. at Scale

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In conjunction with...

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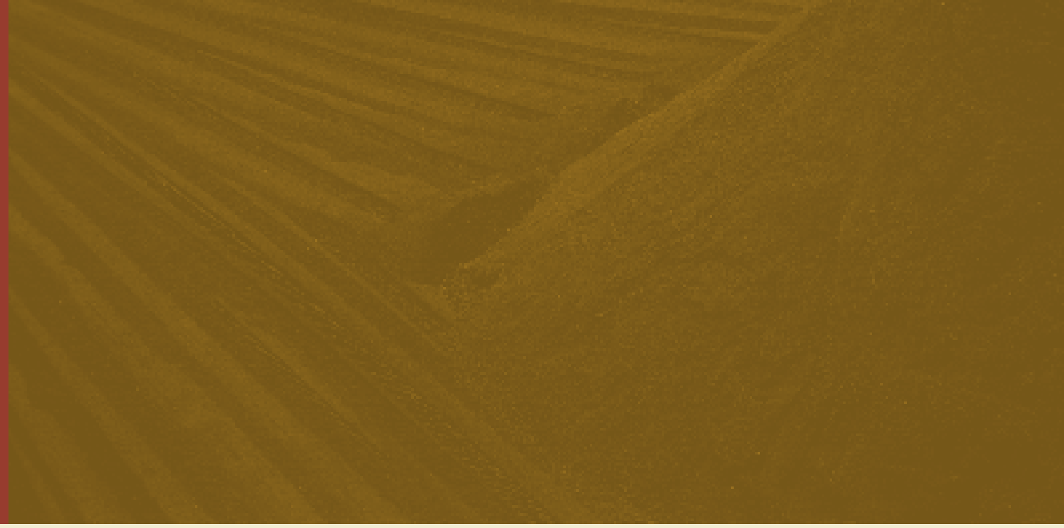


Deploying Climate-Friendly Technologies: A Wedges Approach to Clean Investment

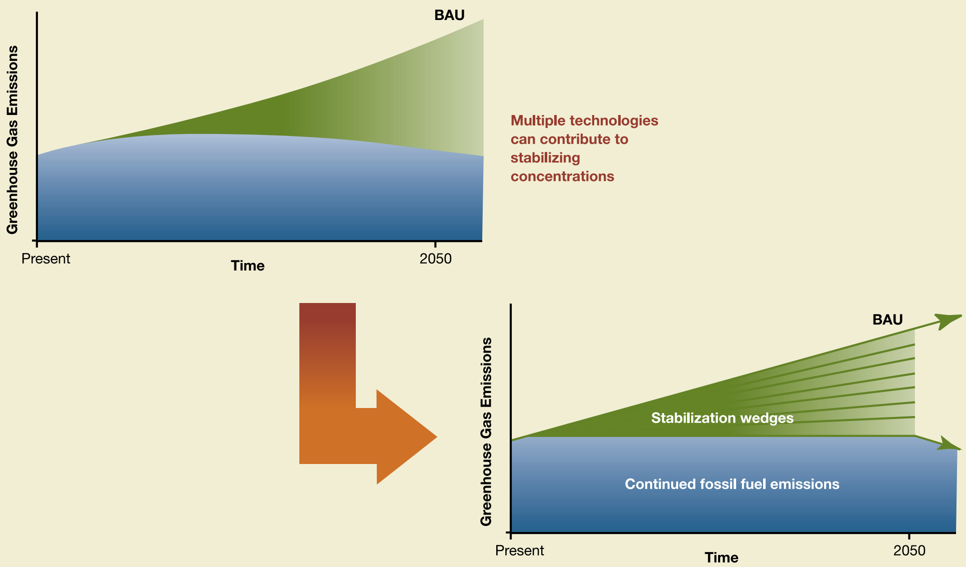
There is no shortage of options and suggestions for how to address climate change. The more difficult task is determining which solutions, or mix of solutions, will reduce greenhouse gas emissions on the scale of what is needed to avoid disastrous climate change impacts.

In the face of rapidly developing economies, population growth, and rising energy demand, it is clear that technology absolutely must be part of the solution. We will need significantly cleaner energy sources than the ones used today. And we need much faster market penetration than has been the historic norm.

In a 2004 *Science* magazine article, Princeton professors Rob Socolow and Stephen Pacala introduced the wedge approach to frame this debate. The idea is elegant and simple. To stabilize emissions in the next 50 years, the world must reduce emissions by about 7 gigatons of carbon (not carbon dioxide) compared to "business as usual" scenarios. So Socolow and Pacala identify 15 stabilization wedges that, if deployed at a significant global scale, could conceivably reduce emissions by 1 gigaton each. At 1 gigaton apiece, each technology wedge still represents a huge investment, but they are nonetheless conceivable.

Seven gigatons of reductions are needed to achieve stabilization, so 7 of 15 wedges would, in theory, reach that goal. If deeper reductions become necessary, additional wedges could be added to the mix.

The Wedges Concept



Source: Pacala and Socolow, Science, 2004. Note: Each "wedge" in this figure represents 1 gigaton of carbon per year; seven wedges are needed if emissions are to be brought back to current levels by 2050 globally – and because of the likely increase in demand, additional efforts would be needed post-2050 to stabilize concentrations. Pacala and Socolow identify options for 15 wedges in their analysis.

The challenge for policymakers is to decide which wedges are preferable, and how to redirect capital toward the deployment of preferred technologies. WRI's climate policy and capital markets projects have teamed up to analyze the best ways to accelerate the global adoption of technologies in the wedge model through government policies, corporate action, and financial investment. In other words, turn the wedge approach into action as quickly as possible.

Foreword

Climate change is at the forefront of today's environmental concerns. The scientific consensus is that climate change is a reality and human activities are largely responsible for the increasing concentrations of greenhouse gases in the earth's atmosphere. Yet we are only beginning to fully comprehend the complex relationships between climatic variation and ecosystem degradation, biodiversity, clean water access and poverty.

While the world focuses on many of the damaging implications of global warming, we hear less frequently about the opportunities that climate change presents. Many of the world's leading companies, including Goldman Sachs and other large financial institutions, have implemented impressive and far-reaching environmental programs. Many companies are discovering that taking steps to mitigate the environmental harm of their operations ultimately produces important benefits to their businesses, including lower energy costs, more efficient business practices, less waste, new business opportunities and markets, satisfied customers and more engaged employees. In short, responding to climate change is a very smart way to do business.

Yet business action alone is insufficient, both in scale and speed, to sufficiently develop the suite of technologies required to avert a dangerous climate scenario. We cannot lose sight of the fact that government action is vital to addressing the challenge. A number of legislative bills currently pending in both the U.S. House and Senate attempt to put a price on the externality associated with greenhouse gas emissions. This will narrow the cost gap between current and cleaner technologies, but it is unlikely that a carbon price alone will stimulate the levels of investment that are needed to develop the needed technologies fast enough to avoid dangerous levels of greenhouse gas concentrations in the atmosphere. Further policies are needed to stimulate both the scale and pace of technology deployment.

The following research report by the World Resources Institute studies one such opportunity for companies, investors and policymakers to have a significant impact on the global emissions trajectory: carbon capture and storage, or CCS. This process would enable coal-fired power plants to capture their carbon dioxide and store it permanently, preventing its release into the atmosphere. Today, the chain of technologies that comprise the CCS process is complex, expensive and not often well understood in its entirety. Yet the potential importance of this process as a means of addressing the climate challenge cannot be understated. Coal-fired power remains both abundant and inexpensive – in both the United States and key developing regions of the world such as India and China. Leaders of these nations are facing unprecedented domestic and international pressures to balance dramatic growth and associated increases in energy needs with global environmental trade-offs.

As WRI highlights in the following pages, the challenges to scaling up low-carbon solutions are many. For new technologies such as CCS, early government demonstration support to help overcome investor concern is critical. In this respect, the recent cancellation by the U.S. Department of Energy of the FuturGen project does not bode well. For there to be any prospect of achieving significant emission reductions through carbon capture and storage, U.S. climate policy support will need to be in place fairly quickly. Climate change is a complex problem, and with 50 percent of electricity in the United States coming from coal-fired power, CCS should likely be a part of the solution if we are to achieve the necessary emission reductions. We look forward to engaging in considerable discussion – and meaningful action – with our clients and partners on how to evaluate and potentially bring these technologies to market.

Jonathan Lash
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Executive Summary

Coal is a key fuel source for current and future electric power generation. Coal becomes even more critical when cost of electricity and security of supply issues are viewed in light of other fuel sources such as gas or uranium. Yet coal combustion produces about 1.9 billion tons of CO_2 per year in the U.S., roughly equivalent to all CO_2 emissions from U.S. transport per annum. The burning of coal, with more CO_2 emissions per unit of energy produced than any other fossil fuel, has significant adverse climate change impacts.

One way to reduce carbon emissions from coal-fired power is to capture and store it permanently underground, a process called carbon capture and storage (CCS), also called carbon sequestration. CCS has captured the attention of policymakers, power generators, and environmentalists because of its potential as a bridging technology that will permit the continued use of coal as a fuel source while not contributing to a further destabilization of the climate. A great deal of work is underway to develop and improve the technologies, legal frameworks, and policies required for wide-scale deployment of CCS systems.

The main reason for this interest is that several major world economies, including the U.S., China, and India depend heavily on coal as an energy source. Alternative means of moving to a zero-carbon power mix, including wind or solar (which are dispersed and have variable output) and nuclear power (which raises difficult questions of security and waste disposal) require wrenching changes to our energy systems. CCS apparently offers the prospect of staving off climate disaster while maintaining something near the status quo. Coal can remain central to the energy mix, and CCS makes this possible.

But does it? There is in fact considerable complexity involved in deploying a national CCS system at the scale necessary to achieve significant emissions reductions. Indeed, it amounts to no less fundamental a transformation of the country's energy infrastructure than would a huge-scale adoption of wind energy, for instance. The objective of this paper is to examine the challenges of this transformation under the four broad categories of technology, policy, legal and regulatory framework, and investment, and their implications for CCS as part of the solution to mitigate adverse climate change impacts.

Technology Challenges

- **CCS is not a single technology,** such as a scrubber or a chemical absorption system. It is a combination of processes, from CO_2 separation to compression and injection into underground geological formations. While the component technologies exist today, they are at different points of maturity, and there is limited experience with integrated CCS projects that combine baseload power generation with capture, transport, and long-term storage of CO_2 at scale. Indeed there is not a single integrated CCS project in the United States; the only government-backed demonstration project in existence was cancelled in January 2008 after five years of delay and cost escalation.
- **Supporting infrastructure.** Initial CCS projects are likely to capture CO_2 from locations near existing sequestration capability in the country. However, once those opportunities are exploited, supporting pipeline infrastructure, storage facilities, and monitoring facilities will be required. The eventual deployment of an integrated CCS system at a scale which achieves significant emissions reductions is an undertaking that will require a significant amount of capital investment over a 20-50 year period of time. There are questions around who will build and operate a dedicated CO_2 pipeline system, who will be responsible for long-term storage and monitoring, and who will pay for it.

Policy Challenges

- **Supporting government policies.** It is unlikely that commercial developers will invest in CCS projects unless policymakers help make it happen. We believe that government must play a dual role—on the one hand using its resources to push new technologies into the marketplace, and, on the other hand, creating the price signals that allow markets and investors to pull the technologies across the threshold of cost-competitiveness and towards full commercialization. Moreover, capital investments in infrastructure are made on the basis of a multi-decade lifecycle. Policies and incentives for CCS must have durability over the entire capital deployment period in order to provide comfort to investors that regulations will not materially change over time.
- **Market pull: a price on carbon.** U.S. climate policies that internalize carbon costs into investment decision-making are a first step in deploying low-carbon technologies. Studies indicate a carbon price at which CCS would become an economically attractive compliance strategy range from around \$30/ton CO_2 at a minimum to as much as \$60/ton CO_2. But a high enough price on carbon is only a start. Whether CCS is indeed chosen as a key component of the compliance strategy (along with efficiency improvements, fuel switching, or purchasing allowances) would depend on how the climate policy is designed in terms of the number of allowances, the stringency of the cap, and the structure of regional electricity markets.
- **Market push: government RD&D.** In parallel to climate policies which place a cost on carbon, the government must also pursue measures that push technologies into the marketplace. Given CCS technology premiums it is likely that the necessary price signal will be extremely high and therefore politically intolerable. Early government action to bring down costs is necessary to bring them in the range of likely price signals. Performance standards, funding for research and development, and large-scale demonstration projects encompassing the full CCS system are fundamental to improving the technologies, reducing costs, and mitigating investor risk.

Legal and Regulatory Challenges

- **Legal and regulatory framework.** A comprehensive regulatory framework is required around storage and long-term liability issues. Making CCS economical is not the only action needed to realize a national CCS system at scale. Regulatory and legal considerations with respect to transport, injection, storage, monitoring, and long-term liability are needed to ensure that CCS projects are safe and effective. The current patchwork of regulations for both CO_2 transport and use will hinder the application of CCS at scale.
- **Leakage and long-term storage** are the most contentious areas of liability. To address climate change, injected CO_2 must remain underground for hundreds or thousands of years, therefore, determination of liability for leakage and defining responsibility to manage and monitor the CO_2 after the sequestration site has been plugged and closed is important. Leakage of CO_2 in high enough concentrations would negate some of the benefits of sequestration and present risks to humans, water supply, and property. It is unlikely that any commercial operation would agree

to assume responsibilities indefinitely. Government may need to assume responsibility at some point, and then there must be sufficient public funds for managing the site over the long-term.

- **Public acceptance.** Even if demonstration projects show CCS risks to be relatively low, public perception of these risks is another matter. A pessimistic public has the potential to invalidate the CCS option if there is a perception that CCS involves long-term storage issues and safety risks. Mostly, this relates to opposition to having a CCS project near one's home, school, or office (referred to as "not-under-my-back-yard" or NUMBY).

Investment Challenges

- **The real cost involved.** Plants that capture CO_2 are more expensive to build than conventional coal plants. In addition, a full CCS system will have costs attached to the compression, transportation, injection, storage, and monitoring of the captured CO_2. Assumptions around new coal capacity build-out, as well as how technology and power project costs will move are very fluid. However, it is likely that with current coal plant costs around $3,000/kW, plus premiums for CO_2 capture and storage, de-carbonizing 76 GW (our estimated size of a U.S. CCS "wedge" by 2030) of coal-fired power would cost hundreds of billions of dollars.
- **Lack of technology performance guarantees.** Typically, in the construction of conventional power plants, contractual performance guarantees are used to manage the risk that the plant will be constructed within the agreed upon budget, timeframe, and performance specifications. In the current construction environment, firms have indicated a reluctance to extend the same performance guarantees for new and untested technologies such as coal-fired integrated gasification combined cycle (IGCC) units. While this issue would be mitigated once a track record is established, it is a critical hurdle for those seeking to finance commercial scale IGCC plants *today*.
- **Cost of technology will come down only incrementally.** Provided that investors obtain the appropriate guarantees and finance the initial plants, experience with construction and operation can be expected to bring CCS technology premiums down. The rule of thumb for new technologies in general is 20 percent unit cost reduction for a doubling of cumulative installed capacity. However, as CCS is *not a single technology,* but rather a combination of processes and technological change will occur via incremental improvements to component technologies.
- **Power project costs are rising.** While technological learning could decrease costs over time, construction costs for all power generating technologies have nearly doubled in recent years. Coal plants are more capital intensive than other technologies like renewables and natural gas and rising materials cost hit it harder than these technologies. With escalating costs of raw materials, construction, and labor, the additional premiums commanded by advanced coal technologies may become prohibitive.

Conclusion

No country has yet grasped in its policy the magnitude of change that any climate "wedge," including CCS, will demand. The U.S. in particular shows a significant gap between rhetoric and action. Despite regular references to CCS in public discourse, the demise of the expensive FutureGen demonstration project in early 2008 implies a different reality. It implies that CCS is still viewed as a painless option, to be overlaid on an essentially business-as-usual development of the energy sector.

This report suggests that as long as this attitude persists there is little prospect of achieving a "wedge" of emissions reductions through CCS. For there to be any such prospect, U.S. climate policy support will need to be ramped up—and swiftly. This will likely require not only a carbon price significantly higher than that in the European Union Emission Trading System today, but also early demonstration support to help overcome investor concern regarding technology performance risk. Above all, CCS needs to be understood as a systems approach, in which other factors such as siting questions, rules for liability, and the building of an infrastructure for CO_2 transportation and storage will need separate but urgent attention.

We recognize that the challenge of climate change is a complex one, and no solution to reducing emissions is without significant constraints. Stabilizing atmospheric concentrations of GHGs to meaningful levels requires pursuing a range of technology options deployed in concert, and CCS may well turn out to be an important part of the solution. To determine that, however, requires a more far-reaching and urgent set of activities from both the public and private sectors than are currently being deployed.

Introduction

Climate change is no longer simply an environmental issue. It is rapidly becoming one of the defining forces of economic development in the 21st century. It will shape investment, technology deployment, and human development around the world, and no sector will be more profoundly affected than energy. Given the constraints that climate impacts bring, thriving in the evolving global energy market will mean understanding the risks and opportunities presented by the public policy choices made in reducing emissions and the infrastructure and financing that is required to implement these choices.

The scientific consensus on man-made climate change is now firmly established. It is explained in the recently released report of the Scientific Working Group of the Intergovernmental Panel on Climate Change (IPCC) which has "very high confidence" that the observed warming trend around the globe is attributable to the net effect of human activities since 1750.[1] In IPCC terms, this means there is at least a 90 percent chance that global warming is human induced. In fact, the IPCC offers no other scenario that could account for the magnitude of change.

The great majority of the impacts expected from climate change are due to the use of fossil fuels, which account for 80 percent of energy demand worldwide and are projected to remain the largest source of primary energy globally.[2] The International Energy Agency (IEA) projects that oil demand will grow by almost 40 percent by 2030 and gas demand will more than double in the same period.[3]

In order to produce electricity to run our homes, businesses, factories, and industrial processes, global electricity generation is projected to double from 17,408 terawatt hours (TWh) to 33,750 TWh in 2030.[4] Most of that demand increase stems from developing countries, in particular China and India as they industrialize. However, continued growth is expected in the OECD and the U.S. with electricity demand in the U.S. projected to increase 40 percent by 2030.[5] The question is

[1] IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

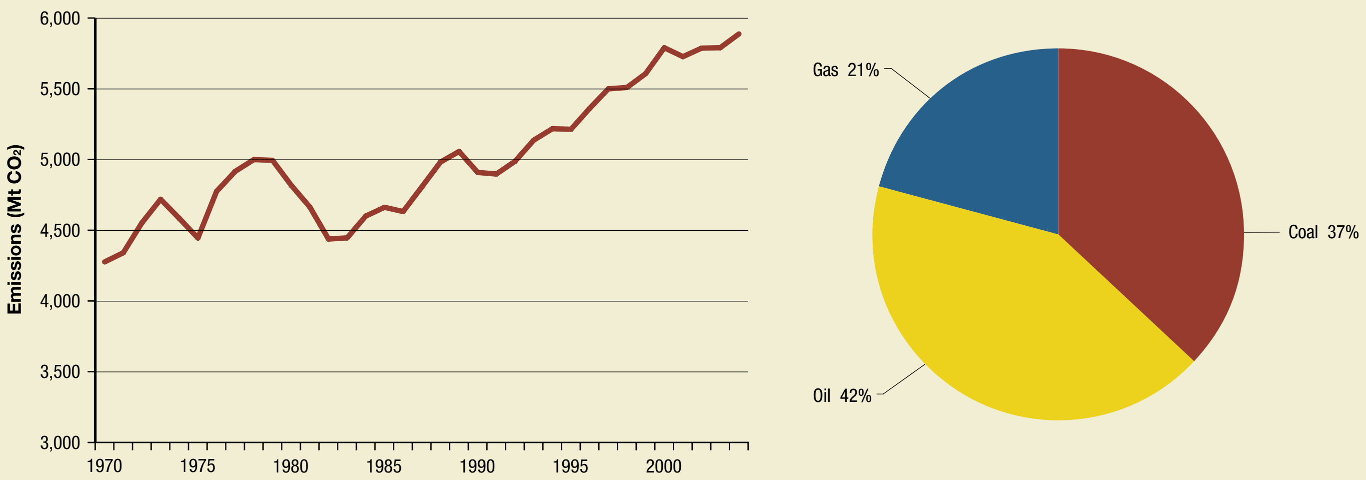
[2] Organization for Economic Cooperation and Development (OECD) and the International Energy Agency (IEA). *World Energy Outlook.* 2006. Paris: OECD/IEA.

[3] OECD/IEA. *World Energy Outlook.* 2006.

[4] OECD/IEA. *World Energy Outlook.* 2006.

[5] OECD/IEA. *World Energy Outlook.* 2006.

Figure 1: **U.S. CO_2 Emissions and Share by Fuel**



Source: World Resources Institute, Climate Analysis Indicators Tool and IEA, World Energy Outlook 2006

how the new capacity needed to meet projected demand will be fuelled, and what will be the impacts associated with those choices (see Figure 1).

Coal's Role in the Energy Mix

Rising oil and natural gas prices, coupled with the fact that these resources are predominantly found in unstable parts of the world, lead to critical cost and energy security issues. While nuclear energy can be expected to be part of the energy mix, its role may be limited. Reactor designs have improved, but the threat of weapons proliferation and issues around long-term storage of radioactive waste are unresolved. Renewable energy, such as solar and wind, also faces considerable challenges to growth. While relative cost is often cited as the primary barrier to growth, the fact that these resources are not yet suitable for producing reliable baseload power is a more fundamental impediment to these technologies achieving a larger share of the energy mix. Energy efficiency can play some role but will likely be unable to deliver the scale of emissions reductions needed.

This leaves coal. Coal is abundant. With 271 billion short tons of U.S. reserves there is enough to last the U.S. for about 234 years at 2006 production levels.[6] It is also relatively cheap at $1.77 per MMBtu compared with $7.05 per MMBtu for natural gas.[7] Finally, coal is less prone to geo-political risk as most coal supplies are located in relatively stable parts of the world. These attributes are clearly reflected in the fact that coal already accounts for roughly 50 percent of electricity generation in the U.S. (see Figure 2).[8] The problem is that the burning of coal has significant adverse climate change impacts. Due to its high carbon content, CO_2 emissions from coal combustion are higher per Btu of heat energy produced than other fossil fuels.[9]

Modeling exercises also indicate a heavy reliance on coal to meet future electricity demand. In 2006, the IEA estimated that roughly 60 percent of the forecasted growth in electricity demand in the U.S. will come from new coal-fired electricity generation.[10] In 2007, the National Energy Technology Laboratory (NETL) forecasted the construction of 151 new coal plants by 2020, representing a total capacity of 90 GW.[11] However,

[6] British Petroleum. "BP Statistical Review of World Energy." June 2007. Available online at: www.bp.com/statisticalreview.

[7] Energy Information Administration (EIA). "Electric Power Monthly February 2008." Washington, DC. Prices are quoted as 2007 average with month ending in October 2007.

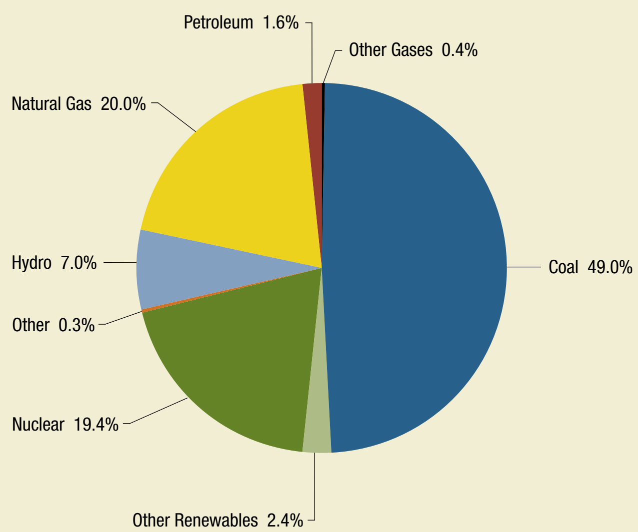
[8] Energy Information Administration (EIA). "Annual Energy Outlook." 2007. Available online at: http://www.eia.doe.gov/oiaf/archive/aeo07/index.html.

[9] In coal plants, CO_2 is emitted in proportion to thermal efficiency (the ratio of heat absorbed to total heat output) where increasing efficiency by one percentage point can reduce CO_2 emissions by around 2-3 percent.

[10] OECD/IEA. *World Energy Outlook.* 2006.

[11] National Energy Technology Laboratory (NETL). "Tracking New Coal-Fired Power Plants: Coal's Resurgence in Electric Power Generation." May 2007.

Figure 2: **Current U.S. Electric Power Mix, 2006**



Source: Energy Information Administration

an increasing number of proposed plants are being canceled or postponed in the face of recent cost overruns and concerns about CO_2 emissions.[12] Investors and financiers are increasingly aware of the issues surrounding coal plants, and weary of investing capital in new plants that are not considered environmentally clean.

Despite this scaleback, coal is, and will likely remain, a major fuel source in the U.S. for the foreseeable future. The question is how to continue to utilize this fuel source while not contributing to a further destabilization of the climate system. Carbon capture and storage could be an important bridging technology as the country moves to a low-carbon economy, enabling it to meet its energy needs while reducing critical emissions that contribute to climate change.

A CCS Climate Wedge

Since 2004, the "wedges" model for climate protection proposed by two Princeton University researchers, Stephen Pacala and Robert Socolow, has been widely used to illustrate the scale of application needed to mitigate climate change using today's technologies.[13] The wedges model divides the emissions reductions needed by 2050 into discrete technological measures, each of which reduces emissions relative to a business as usual (BAU) projection by one gigaton of carbon (GtC).[14] While each of these represents a daunting task, they rely on existing technologies, or some incremental improvement of them. It is estimated that implementation of at least seven such wedges will be required to limit climate change to less than catastrophic levels. One suggested wedge is geological storage of CO_2 from baseland power plants through a process called carbon capture and storage or sequestration (CCS).

Carbon capture and storage requires capturing CO_2 from power plants, transporting it to suitable locations, and injecting it into deep underground geological formations such as saline aquifers and depleted oil and gas fields. Injection of CO_2 in depleted oil fields for the purpose of enhanced oil recovery (EOR) has been done for over 30 years and is a mature market. While there are many small scale CCS pilot projects in the planning phases, well established large-scale projects are few. They include an injection project in Sleipner, Norway; an enhanced oil recovery effort in Weyburn, Canada; and a gas field project in In Salah, Algeria. In the United States, there are currently no projects which fully integrate capture and storage.

There is also potential for coal resources to be utilized in ways that significantly challenge the response to climate change as outlined in the wedges vision. In particular, technologies which transform resources into liquid fuels such as coal-to-liquids, oil shale, and tar sands threaten to increase CO_2 emissions compared with BAU projections, rendering the challenge of fighting climate change far more difficult. This has led WRI to

[12] For example, in June 2007 the Florida Public Service Commission (PSC) rejected a proposal by the Florida Power & Light Company to build a $5.7 billion 1,960 MW coal-fired power facility in Glades County, citing concerns over construction costs and future coal prices. In Kansas, the Department of Health and Environment cited environment and health concerns in denying the air quality permit for Sunflower Electric Power Corporation's two proposed 700 MW generators.

[13] Pacala, Stephen and Robert Socolow. "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies." *Science* 305. 2004: 968-972.

[14] Note: A gigaton of carbon (GtC) can be converted into a gigaton of carbon dioxide ($GtCO_2$) by multiplying by the ratio of the molecular weight of carbon dioxide (44) to atomic weight of carbon (12) or 3.67.

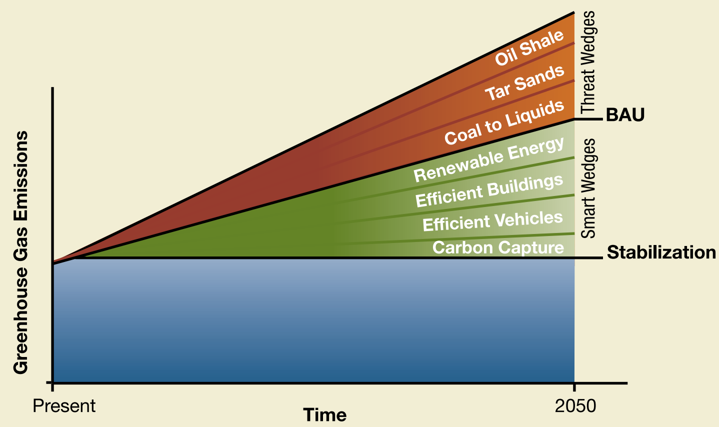
expand the wedges model, introducing the concept of the "threat wedges" to contrast with the "smart wedges" of the original concept (see Figure 3).

Scale is a central factor in the wedges framework. Achieving the scale of emissions reductions as outlined in the wedges model is estimated to require deploying carbon capture and storage on 800 GW of baseload coal capacity worldwide. To put this in context, U.S. coal capacity is presently 334 GW, or 27 percent of the 1,235 GW of global coal-fired capacity.[15] According to projections by the IEA, U.S. capacity will grow to 504 GW by 2030, or 20 percent of global coal-fired capacity at 2,565 GW.[16]

Within this capacity expansion forecast, how much carbon capture and storage capacity would be necessary if the U.S. were to contribute a pro rata share of a global CCS wedge? How much additional CCS capacity would need to be constructed globally if CCS were to play a role in achieving the wedges vision? Making forecasts of global power generating technologies and capacity mix out to 50 years is extremely difficult. The simple calculations which follow are intended for illustrative purposes only and are based on the IEA projections which only provide a context to 2030.

Assuming that a global CCS wedge was deployed at a linear rate, about 17.4 GW per year of construction would be needed to reach 800 GW by 2054. Applying this linear construction rate to the IEA projections, a global CCS wedge would require roughly 382.8 GW of capacity in 2030. The U.S. pro rata share of this global wedge would be calculated by simply multiplying this number by 20 percent, the U.S. share of global coal capacity in 2030. This gives a U.S. wedge of 76 GW by 2030, which translates into about half of the U.S. coal fired capacity that the IEA estimates will be constructed by that time. As can be seen, realizing a 1 GtC wedge from carbon capture and storage deployment will require a global deployment effort engaging the rest of the world, in particular China, which is projected to have twice the emissions levels from all coal-fired plants as the U.S. by 2030 (see Box 1).[17]

Figure 3: **Indicative Illustration of Smart Wedges and Threat Wedges**



Source: World Resources Institute. Note that the wedges are a schematic, indicative, and not drawn to a specific scale.

Box 1: Coal, China, and Technology Transfer

No discussion on coal can take place without addressing China. China obtains 80 percent of its electricity from coal-fired power plants and accounts for 33 percent of global coal demand.[18] With a new coal plant being built almost every week in the country, China may need to consider clean coal burning technologies sooner rather than later.

However, tensions between economic growth and environmental protection goals are particularly acute for large developing countries such as China. At the center of the debate are unaffordable cost premiums on clean technologies and gaps in technical capability. China, as well as India, and other developing countries argue that clean technology transfer from the United States and Europe is crucial to achieving their policy goals.

But potential technology sellers in industrialized countries have limited interest in sharing design and production capabilities that would increase a developing country's ability to manufacture these technologies themselves. China's weak protection of intellectual property rights (IPR) and its history of replicating imported technology do not help.

Low-carbon technology transfer is currently included in the Kyoto Protocol as a voluntary initiative. Industrialized countries are encouraged, under the agreement, to give technological advice to less developed countries. Today, China is looking to move the debate forward by suggesting that technology transfer should be a mandatory obligation for developed countries and that a fund should be set up for that purpose.

Clearly technology sharing is critical to addressing a global problem such as climate change. Collaborative efforts with developed countries need to be put in place in order to support joint R&D efforts. In addition, intellectual property rights and perceived competitive risk need to be addressed to attract foreign investment.

[15] OECD/IEA. *World Energy Outlook.* 2006.

[16] OECD/IEA. *World Energy Outlook.* 2006.

[17] According to the IEA, China will account for 1,041 GW of the 2,565 GW global coal-fired capacity in 2030. OECD/IEA. *World Energy Outlook.* 2006.

[18] OECD/IEA. *World Energy Outlook.* 2006.

This Report

This report aims to evaluate CCS in the context of climate stabilization wedges and the challenges and opportunities linked to its wide scale deployment. WRI examines the impacts and trade-offs related to a fully integrated CCS system in the United States, placing its analysis within the framework outlined in, *Scaling Up: Global Technology Deployment to Stabilize Emissions*, the introductory piece for this report.

This report first examines the **technologies** that comprise CCS, exploring the state of development of each component technology and how mature the technology is, as well as who the early adopters in the market place are. It then turns to the **policy** structures that drive a transition to a low-carbon economy, examining both government "push" strategies such as research and development and market "pull" strategies which place a price on carbon. It also discusses key regulatory needs such as a legal framework around long-term storage and the thorny issue of public acceptability. The final section analyzes some of the resulting drivers for **investment** and argues that cost premiums on advanced coal technologies, escalating capital costs for coal plants in general, and the lack of technology performance guarantees will make the rapid scale-up of integrated CCS systems particularly challenging. Examples of noteworthy companies and collaborative partnerships in the U.S. seeking to address barriers to CCS deployment are highlighted throughout.

WRI concludes that a shift to a more environmentally and economically attractive low-carbon energy future in the U.S. underpinned by an economically viable national CCS system is possible, but it requires a more far-reaching and urgent set of activities from both the public and private sectors than is currently the case. Such a fundamental shift will likely only occur once definitive policies and incentives are put in place that reward investment in and capital formation around improved carbon performance. The near-term demonstration of commercial scale CCS plants, meanwhile, will be an important step toward the longer-term goal of large-scale rollout.

Technologies Involved in CCS Systems

Unlike pollution control technologies such as scrubbers that are simply fitted on, CCS is *not a single technology*. It is a combination of processes that, in addition to capturing the CO_2 that is produced, involves technologies which compress, transport, inject, and monitor it. While all the component technologies exist today, and a complete CCS system can be assembled from them, the state of development of the component technologies is at different points on the maturity scale. Moreover, the state of development of a fully integrated CCS system is less than some of its separate components (see Figure 4). The industry has very limited experience with projects that integrate capture, transport, and long-term storage of CO_2 at scale to produce commercial baseload power. This section will highlight the components, processes, and technologies that make up a fully integrated CCS system.

Capture Technologies

Carbon dioxide capture requires separating CO_2 from industrial and energy-related 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, and coal-to-liquid plants are currently targeted as candidates for CCS.

There are four methods for capturing CO_2. Post-combustion capture involves separation of the CO_2 from the flue gas, and would be applied to subcritical pulverized coal (PC), supercritical pulverized coal (SCPC), or ultra-supercritical pulverized coal (USCPC). In post-combustion separation, the CO_2 is typically absorbed into an amine solution and then stripped via a temperature increase. Carbon dioxide can also be separated and captured from fuel *before* it is burned. In pre-combustion separation, a physical solvent is used to separate the CO_2 from the syngas via a pressure decrease. Integrated gasification combined cycle (IGCC) power plants use this approach for carbon capture which is easier and thus much less expensive. Oxy-fuel combustion is a third, emerging option, which uses oxygen instead of air for combustion and produces a concentrated CO_2 exhaust stream. Finally, CO_2 can also be captured in limited quantities from industrial practices that do not involve fuel combustion, such as natural gas purification.

In all cases, capturing CO_2 incurs an "energy penalty" because energy is diverted to capture and compress the CO_2. This reduces steam to the turbine and therefore net power output of the generating plant. To maintain existing net power generation the coal input must be increased, as well as the size of the boiler, the steam turbine and generator, and the equipment for flue gas clean-up. Different fuel characteristics and operating environments will also have an impact. The energy penalty increases the cost of plants with capture and the amount of coal used.

Post-combustion is now the most mature operation, although it is expensive and energy-intensive to apply carbon capture. Pre-combustion capture utilizing IGCC is estimated to have the lowest overall costs when capture is applied, although experience with the technology for commercial power generation is limited and without carbon capture costs tend to be higher. Oxy-fuel combustion is still in the demonstration phase, and more testing—particularly at larger scales—is needed. CO_2 capture from industrial processes is a mature market but is not expected to contribute to significant abatement of emissions.

Figure 4: **Technical Components of Carbon Capture and Storage**

CCS Component	CCS Technology	Research Phase[a]	Demonstration Phase[b]	Economically Feasible Under Specific Conditions[c]	Market Mature[d]
Capture	Post-combustion			■	
	Pre-combustion			■	
	Oxyfuel combustion		■		
	Industrial seperation				■
Transport	Pipelines				■
	Shipping			■	
Geological Storage	Enhanced oil recovery (EOR)[e]				■
	Gas or oil fields			■	
	Saline formation			■	
	Enhanced Coal Bed Methane Recovery (ECBM)[f]		■		
Ocean Storage	Direct injection	■			
Mineral Carbonation	Natural silicate minerals	■			
	Waste materials		■		
Industrial uses of CO_2					■

[a] Research phase means that the basic science is understood, but the technology is currently in the stage of conceptual design or testing at the laboratory or bench scale, and has not been demonstrated in a pilot plant.

[b] Demonstration phase means that the technology has been built and operated at the scale of a pilot plant, but further development is required before the technology is ready for the design and construction of a full-scale system.

[c] Economically feasible under specific conditions means that the technology is well understood and used in selected commercial application, for instance if there is a favorable tax regime or niche market, or processing in the order of 0.1 $MtCO_2$ yr, with few (less than 5) replications of the technology.

[d] Mature market means that the technology is now in operation with mulitiple replications of the technology worldwide.

[e] CO_2 injection for EOR is a mature market technology, but when used for CO_2 storage, it is only economically feasible under specific conditions.

[f] ECBM is the use of CO_2 to enhance the recovery of the methane present in unminable coal beds through the preferential absorption of CO_2 on coal. Unminable coal beds are unlikely to ever be mined because they are too deep or too thin. If subsequently mined, the stored CO_2 would be released.

Source: IPCC Special Report on Carbon Dioxide Capture and Storage

Box 2: The Market for CCS Technologies—Early Stage Adopters

Early stage technology diffusion is critical for bringing down costs and thereby encouraging adoption at scale. Establishing a track record for CCS technology through market experience is vital at this point in time. Activity by early market movers will be critical in the emergence of a new low-carbon economy, while technology performance guarantees will be important for investors to step up with the financing. The fact that both vendors and potential buyers are showing interest in the various component technologies has positive implications for an eventual commercial scaling up of CCS systems.

Although gasification is commonly used in the chemical industry, only a few IGCC projects have been built worldwide for electric generation due to the higher capital and operating costs compared to pulverized coal plants. There are two commercially operating IGCC plants in the U.S. used for electricity generation. Both were supported initially under the Department of Energy's (DOE) Clean Coal Technology Demonstration Program (CCTDP) but now operate commercially without DOE support.

The first is the 262 MW Wabash River Coal Gasification Re-powering Project in Indiana which began operation in 1995 and uses the E-Gas gasification technology acquired by ConocoPhillips in 2003. The second is the 250 MW Polk Power Station owned by Tampa Electric, which began operation in 1996 using the Texaco gasification technology acquired by General Electric in 2004.

Neither of these projects actually capture and sequester the CO_2 emissions. However, they do provide valid demonstrations of IGCC's performance characteristics for anticipated capacity, efficiency, and CO_2 emissions. Although the projects have experienced higher costs and raised some concerns over reliability, lessons are emerging to improve both the technology and operating process, and the industry is encouraging suppliers to offer performance guarantee contracts for the technology.

On the supplier side, despite the fact that CCS technologies carry higher costs and risks, recently suppliers have begun to emerge that offer comprehensive, integrated designs with packaged systems and compatible equipment for next-generation power plants. Shell and ConocoPhillips have led the commercialization of gasification technology. In 2004, General Electric acquired Texaco's gasification technology and was soon engaging experts from throughout the gasification industry at both operating and research levels to develop the most economical and reliable approaches to IGCC technology.

Meanwhile, on the buyer side, companies such as Entergy, Xcel Energy, American Electric Power (AEP), and NRG Energy could be considered early movers as they state they would like to include IGCC technology in their fleets and are following the development of the technology. AEP intends to add one or more 600 MW units of baseload IGCC generation to its portfolio. In November 2007, NRG Energy and Powerspan Corp. announced a commercial scale demonstration project to capture CO_2 from a 125MW coal power plant in Parish, Texas.

As power producers realize the benefits of fuel flexibility and low emissions, a key development has been the Electric Power Research Institute and a number of utilities coming together to form the *Coal Fleet for Tomorrow* project, designed to accelerate the deployment of clean, efficient, advanced coal technology.[19] While initially concentrating on developing IGCC technology, Coal Fleet for Tomorrow will also address other advanced coal technologies such as ultra-supercritical pulverized coal and supercritical circulating fluidized bed combustion, to support their commercial availability by 2015 to 2020.

Compression Technologies

Compression into a supercritical fluid is required to make CO_2 easier and cheaper to transport. CO_2 compression uses the same equipment and techniques as natural gas compression, with some modifications to suit the properties of CO_2.[20] Avoiding corrosion is the main additional operating issue when dealing with CO_2. Since CO_2 dissolves in water and forms carbonic acid, which is corrosive, minimizing the water content in the CO_2 stream is essential for safe operation of the compressor. Gas compression is a mature, well developed technology in the natural gas industry. Millions of tons of CO_2 have already been compressed, transported, and injected in the U.S. for enhanced oil recovery (EOR) operations. There is more than adequate operating experience in compressing and handling CO_2 in large-scale applications in this country.

Transport Technologies

After capture and compression, the CO_2 waste stream must be delivered from the point source to the sequestration site. Transport technology is considered relatively mature, at least relative to capture and underground sequestration. Dedicated CO_2 pipelines are the most efficient transport mode for shipment, but tanker trucks and ships can be used. There are over 3,600 miles of pipelines dedicated to CO_2 transport in the U.S., mainly for used in EOR projects (see Box 3).[21] These CO_2 pipelines have been successfully operated since the early 1970's and there is considerable expertise in this area in the United States. The Cortez pipeline, for example, delivers CO_2 over a distance of 500 miles from natural CO_2 deposits in Southwest Colorado to the Denver City hub in Texas. Most of the EOR projects in the U.S. are in the Permian Basin of West Texas and tap naturally occurring CO_2 sources, which is easier than capture from plants.

[19] *Coal Fleet for Tomorrow* is an industry imitative by the Electric Power Research Institute (EPRI) to accelerate the deployment of advance coal-based generation plants.

[20] Harwood, Jennifer. "Building Capacity for CO_2 Capture and Storage in the APEC Region." March 2005. The Delphi Group. Available online at: http://www.nrcan.gc.ca/es/etb/cetc/combustion/co2network/pdfs/apec_training_2005.pdf.

[21] Parfomak, Paul and Peter Folger. "Carbon Dioxide (CO_2) Pipelines for Carbon Sequestration: Emerging Policy Issues." April 2007. Congressional Research Service (CRS). Available online at: http://assets.opencrs.com/rpts/RL33971_20070419.pdf.

However, if CCS is to have a significant impact on emissions beyond what is possible from EOR operations and initial demonstration projects, this would require new pipelines to transport the massive quantities of CO_2 involved. How it will develop would largely be a function of the proximity of storage sites to power plants. Some assessments indicate that a large majority of fossil fuel plants are within a 100 mile distance of a potential reservoir, in which case pipelines may be structured in localized or regional networks spanning a few states.[24] On the other hand, pipeline siting constraints and regional sequestration issues could require longer transportation distances. A more centralized CO_2 pipelines scenario may develop around a pipeline "hub" system to which multiple power plants and priority storage sites can be connected. Generally, the extent of these systems will be determined by the heterogeneity of underground storage capacity and cost of construction and operation of long pipelines.

Carbon dioxide could also be transported via ships, although shipping is generally more suitable for shorter distances and for picking up CO_2 from smaller and/or scattered sources. While transporting CO_2 by ship is an established technology on a smaller scale, the quantities of CO_2 involved at wedge scale are enormous and present an altogether different challenge in terms of shipping capacity. There is some experience from shipping CO_2 in connection with food production and industrial use of the gas but at smaller volumes than would be required for CCS. Other challenges include regularity of supply and cost-effective unloading of CO_2 from a ship to an offshore installation. One alternative to shipping directly to an offshore installation is to ship to an intermediate storage facility on land which is linked by pipeline to the offshore field.

In the U.S., a variety of agencies will need to coordinate these developments. State oil and gas commissions, the Federal Energy Regulatory Commission, 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.

Box 3: Enhanced Oil Recovery (EOR)

In the oil and gas sector, there is a great deal of interest in enhancing the production of oil and gas while storing CO_2. EOR can create benefits of up to $55 per ton of CO_2 (excluding the costs of the wells and CO_2 recycling), which can potentially offset part or even total capture costs.[22] In most cases though, the costs for CO_2 capture will exceed the benefits of EOR and additional incentives will be needed. Also, the potential for EOR is limited due to the limited number of sites and total oil that could be recovered through enhanced recovery.

However, it is likely that early CCS projects will evolve or expand in connection with EOR. For example, the Weyburn project in North America is capturing CO_2 from the Dakota Gasification Company facility. The CO_2 is transported approximately 200 miles and injected at the Weyburn field to facilitate additional oil extraction and is also sequestered and monitored. Over the life of the Weyburn project (20-25 years) it is expected that that some 20 Mt CO_2 will be stored in the field.[23]

The attraction of EOR from an emissions reduction point of view is that the cost advantage could potentially encourage early adopters of CCS technology. Thus, some believe that EOR may be a way to spearhead commercial deployment and an infrastructure build-out for regular carbon capture and permanent sequestration.

Sequestration Technologies

Sequestration refers to the process of injecting CO_2 into deep reservoirs, such as depleted oil and gas fields and saline aquifers. Various trapping mechanisms prevent the CO_2 from migrating to the surface. The primary trapping is a layer of impermeable caprock overlying the sequestration site. 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.

The first question is whether there is sufficient storage capacity to accommodate the volumes of captured CO_2. It is difficult to quantify proven capacity, however, most estimates of global sequestration capacity range from two trillion tons of CO_2 to 11 trillion tons, which is likely enough capacity to accommodate several decades or perhaps more than a century's worth of global emissions.[25] In addition, the U.S. Department of Energy (DOE) has taken further steps to assess carbon sequestration potential in the U.S. and Canada through the seven Regional Carbon

[22] Organization for Economic Cooperation and Development (OECD) and the International Energy Agency (IEA). *Prospects for CO_2 Capture and Storage.* 2004. Paris: OECD/IEA.

[23] IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H.C. de Coninck, M. Loos, and L.A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

[24] Dahowski, R.T. and J.J. Dooley. "Carbon Management Strategies for U.S. Electricity Generation Capacity: A Vintage-based Approach." *Energy* 29. 2004: 1589-1598.

[25] IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H.C. de Coninck, M. Loos, and L.A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp. and Dooley, J. et al. "Carbon Dioxide Capture and Geologic Storage: A Core Element of a Global Energy Technology Strategy to Address Climate Change." 2006. Battelle Memorial Institute.

Box 4: Department of Energy (DOE) Regional Carbon Sequestration Partnerships

The Regional Carbon Sequestration Partnerships are a collaborative effort between government and industry tasked with determining the most suitable technologies, regulations, and infrastructure needed for the successful and effective deployment of CCS in different areas of the United States.

There are seven regional partnerships including a network of over 350 state agencies, universities, and private companies, spanning 41 states, two Indian nations, and four Canadian provinces. The Regional Partnerships' initiative is being implemented in three phases:

- Characterization Phase (2003-2005), involved characterizing the opportunities for carbon sequestration in the seven partnership regions.
- Validation Phase (2005-2009), currently under way; in this phase small scale injection tests are being conducted to understand the subsurface CO_2 movements.
- Deployment Phase (2008-2017), during this phase large scale CO_2 storage will be conducted.

The regional partnerships have begun the task of engaging local, state, and federal regulators as well as the general public and the private sector. To date, none of the 25 pilot projects have been opposed, largely due to outreach programs that seek to actively engage the community in the initial stages, with the goal of understanding their concerns and developing mutually acceptable means of addressing them.

For more information on Regional Partnerships please visit: http://www.netl.doe.gov/technologies/carbon_seq/partnerships/partnerships.html

Sequestration Partnerships (see Box 4). Efficiently linking potential sequestration sites with sources of CO_2 will be challenging given the volume of CO_2 involved. Potential sites for sequestrating CO_2 underlie a large portion of the U.S., Canada, and Australia, while some nations, such as Japan and South Korea have little sequestration capacity (see Figure 5).[26]

The second question relates to how to identify the best sites for sequestration in terms of safety, permanence, and cost. While sequestration costs are significantly less than those associated with capture, there is considerably less understanding and experience with long-term sequestration. Oil companies have a track record of injecting CO_2 into depleted oil reservoirs but have little experience injecting into deeper saline reservoirs. 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 some of these uncertainties.

Commercial stage sequestration projects include a project in Sleipner, Norway where Statoil operates a commercial gas platform in the North Sea to separate CO_2 from gas and re-inject it 1,000 meters beneath the seabed. Another project operates through a joint venture between British Petroleum, Statoil, and Sonatrach (Algeria's state-owned energy company). The In Salah, Algeria project also removes CO_2 from gas. Finally, in the Weyburn oil field in Saskatchewan, Canada the CO_2 produced by a coal gasification plant in North Dakota is piped across the border for an EOR operation in a partly depleted oil field.

[26] Dooley, J. et al. "Carbon Dioxide Capture and Geologic Storage: A Core Element of a Global Energy Technology Strategy to Address Climate Change." 2006. Battelle Memorial Institute.

Figure 5: **Regional Carbon Sequestration Partnerships, Validation Phase Geologic Field Tests**

Partnership	Geologic Province	Formation Type	Total CO_2 Injection (tons CO_2)	Approximate Depth (feet)
Big Sky Carbon Sequestration Program	Columbia Basin	Saline formation (basalt/mafic)	3,000	3,255 - 3,335 & 3,600 - 3,755
Midwest Geological Sequestration Consortium	Illinios Basin	Saline formation	10,000	7,000 - 8,600
	Illinios Basin	Oil-bearing - Heavy	300	1,550
	Illinios Basin	Oil-bearing - Well Conversion	300	1,549
	Illinios Basin	Oil-bearing - Pattern Flood I	300	1,548
	Illinios Basin	Oil-bearing - Pattern Flood II	300	1,551
	Illinios Basin	Coal seam	750	1,000
Midwest Regional Carbon Sequestration Partnership	Cincinnati Arch	Saline formation	1,000 - 3,000	3,200 - 3,500
	Michigan Basin	Saline formation	3,000 - 20,000	3,200 - 3,500
	Appalachian Basin	Saline formation	1,000 - 3,000	5,900 - 8,300
Plains CO_2 Reduction Partnership	Keg River Formaton	Oil-bearing	250,000 tons CO_2 with 90,000 tons H_2S	5,000
	Duperow Formation	Oil-bearing	5,000	10,000 - 10,500
	Williston Basin	Coal seam	<1,000	1,600 - 1,800
Southeast Regional Carbon Sequestration Partnership	Gulf Coast	Oil-bearing	>800,000/yr	10,066
	Gulf Coast	Saline formation	30,000	10,300
	Mississippi Salt Basin	Saline formation	3,000	8,600
	Central Appalachian	Coal seam	1,000	1,600 - 2,300
	Black Warrior Basin	Coal seam	1,000	1,500 -2,500
Southwest Regional Partnership on Carbon Sequestration	Paradox Basin, Aneth Field	Oil-bearing	450,000 - 750,000	5,600 - 5,800
	Permian Basin	Oil-bearing	900,000	5,800
	San Juan Basin	Coal seam	75,000	3,000
	Paradox Basin, Aneth Field	Saline formation	20,000	6,900
West Coast Regional Carbon Sequstration Partnership	Thorton Gas Field	Saline formation	1,000	3,400 - 3,500
	Thorton Gas Field	Gas-bearing	500	3,050
	Colorado Plateau	Saline formation	2,000	5,000

Source: U.S. Department of Energy, Carbon Sequestration Atlas of the United States and Canada, 2007

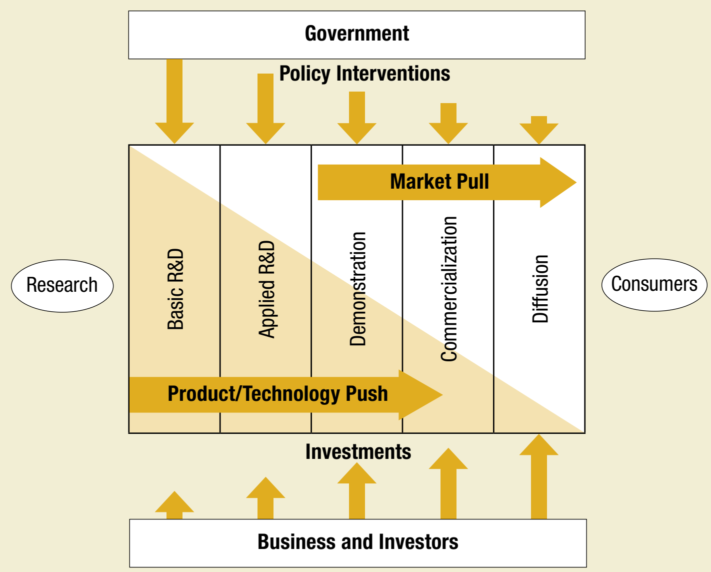
CCS Deployment Depends on Policy Design

The transition to a lower-carbon energy economy is a long-term one. It takes a long time to influence the overall direction of the energy system. Power plants and transport infrastructure require major investments that will last 25 to 50 years and more. Policies and programs have to be in place now to encourage innovation and reinvention when energy infrastructure is replaced, upgraded or expanded in the future. They also have to be viewed as durable over the lifespan of a highly capital intensive project and not affected by the changes in incentives enacted from one political cycle to another.

Far-sighted policy design and the prudent dedication of public resources and incentives are indispensable to a scaled-up national carbon capture and storage effort. Commercial players are unlikely to engage unless U.S. climate policy mandates it in some way or makes it cost effective. Historically, the power producer based technology choices on relative fuel costs and capital costs. Today the power industry must also give serious consideration to federal and state policies being developed to reduce carbon emissions that will eventually create future carbon liabilities. Although deploying these new technologies increases present capital expenditure, that expenditure could offset future compliance costs. CCS, however, is one of many emissions reduction strategies. For CCS to de deployed at scale it must be positioned as the least-cost compliance strategy—i.e. the strategy that will reduce a power plant's expected carbon liability at the cheapest cost.

The government plays a dual role in moving low carbon technologies forward. On one hand, policymakers must use their resources to push new technologies into the marketplace, and, on the other hand, create the price signals that allow markets and investors to take over, ultimately pulling the technologies across the threshold of cost-competitiveness and allowing for full commercialization and scale-up. A government "pull" strategy would center on price incentives through cap and trade or taxation, whereas, a "push" strategy would center on research, development, and demonstration (RD&D); technology performance standards (such as efficiency standards); and subsidies. The two methods are not mutually exclusive but rather complimentary for technologies which are commercially unproven (see Figure 6).

Figure 6: **Technology Innovation Chain**



Source: World Resources Institute based on M. Grubb and R. Stewart, "Promoting Climate-Friendly Technologies: International Perspectives and Issues"

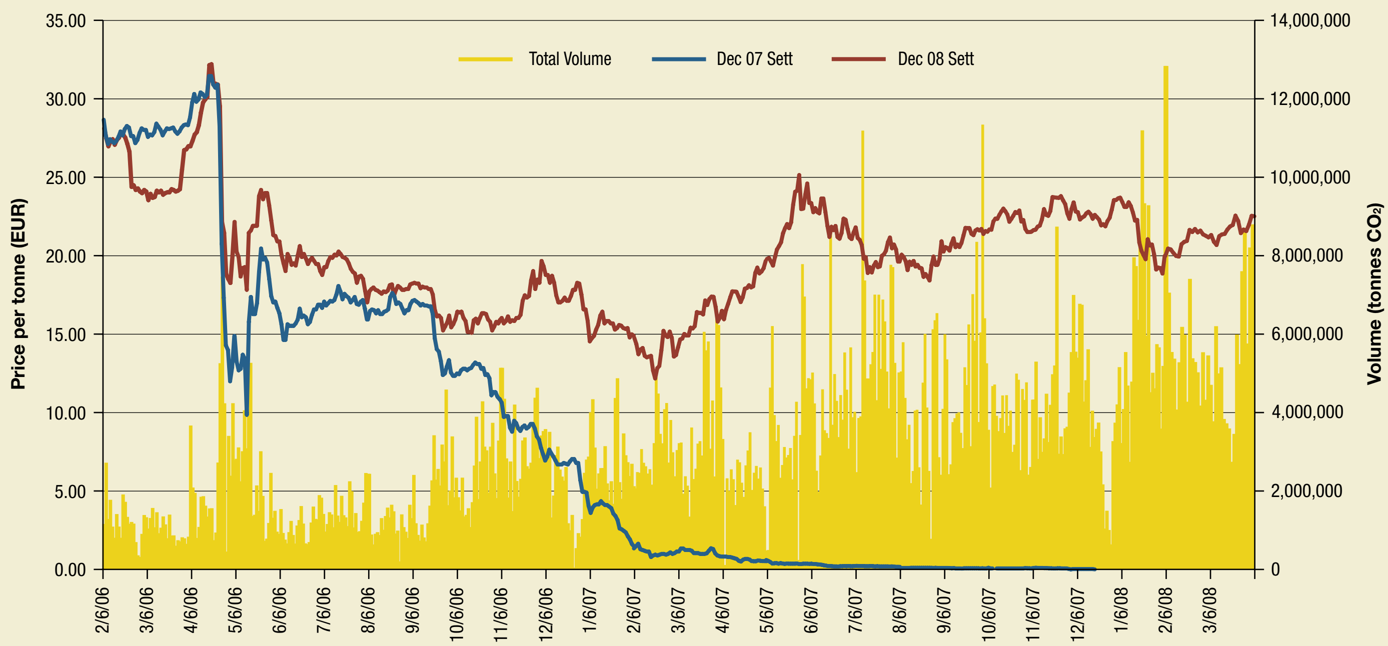
Market "Pull"–Emissions Trading and Carbon Prices

The logic of a market pull strategy is that the government establishes price signals and private firms respond to economic incentives by developing technologies at the lowest possible costs. Based on U.S. culture and prior experience with emissions trading, the centerpiece of U.S. climate policy is likely to be a price on carbon established through a cap-and-trade emissions market. In a recent collaboration between business and environmental organizations called the United States Climate Action Partnership (USCAP), the organizations joined together in calling for strong federal climate legislation that includes market-based incentives, performance standards, cap-and-trade, and tax reform.[27] Perhaps not surprisingly, many in the business community are increasingly supportive of regulatory action due to a perception that the lack of clarity on federal climate policy, coupled with a growing patchwork of state and regional regulation, is likely to be more costly than inaction in the long run.

With respect to CCS deployment, one salient question is how the cap-and-trade system will be designed. Will it make CCS a viable option for compliance versus other strategies to reduce

[27] For more information on USCAP, please refer to its website: www.us-cap.org.

Figure 7: **ECX CFI Futures Contracts: Price and Volume**



Source: European Climate Exchange

CO_2 emissions? Because the allocation to each firm is usually less than its historic emissions, regulated firms have four basic options for compliance:

- Controlling their emissions to match their allocation exactly;
- Buying allowances to cover excess emissions;
- Buying offset credits to offset excess emissions; and
- Selling their unused allowances or banking them for use in future years.

CCS is a compliance option that requires significant capital investments; therefore, the cost of compliance—i.e. the price on carbon—needs to be sufficiently high if CCS is to be an economically viable emissions reduction strategy. A number of studies calculate the price at which CCS may become an economically attractive compliance strategy. For example, modeling exercises conducted by the Massachusetts Institute of Technology (MIT) estimate a CO_2 price over $30/ton[28] while McKinsey suggests a cost around $44/ton CO_2 in its abatement curve analysis.[29] Other research suggests a cost driver ranging from $40-60/ton of CO_2 to make CCS economically feasible at much larger scale power plants.[30] These analyses vary according to the underlying assumptions and may or may not include transport and storage costs. Further, due to recent price escalation for construction services, equipment, and materials these figures are likely to understate the actual carbon value that would make CCS an attractive compliance strategy.

Meanwhile, Europe, which already has a price on carbon under the European Union Emission Trading System (EU ETS), has seen periods of relatively high carbon prices. However, this has not led to investment in higher cost abatement options such as CCS in EU countries. This is largely due not to price but to the fact that allowance allocation in the early phase of the system was not optimally designed to stimulate low-carbon technology

[28] Massachusetts Institute of Technology. *The Future of Coal: Options for a Carbon-Constrained Economy.* 2007. Available online at: http://web.mit.edu/coal/

[29] McKinsey & Company. "Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?" December 2007. Available online at: http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf.

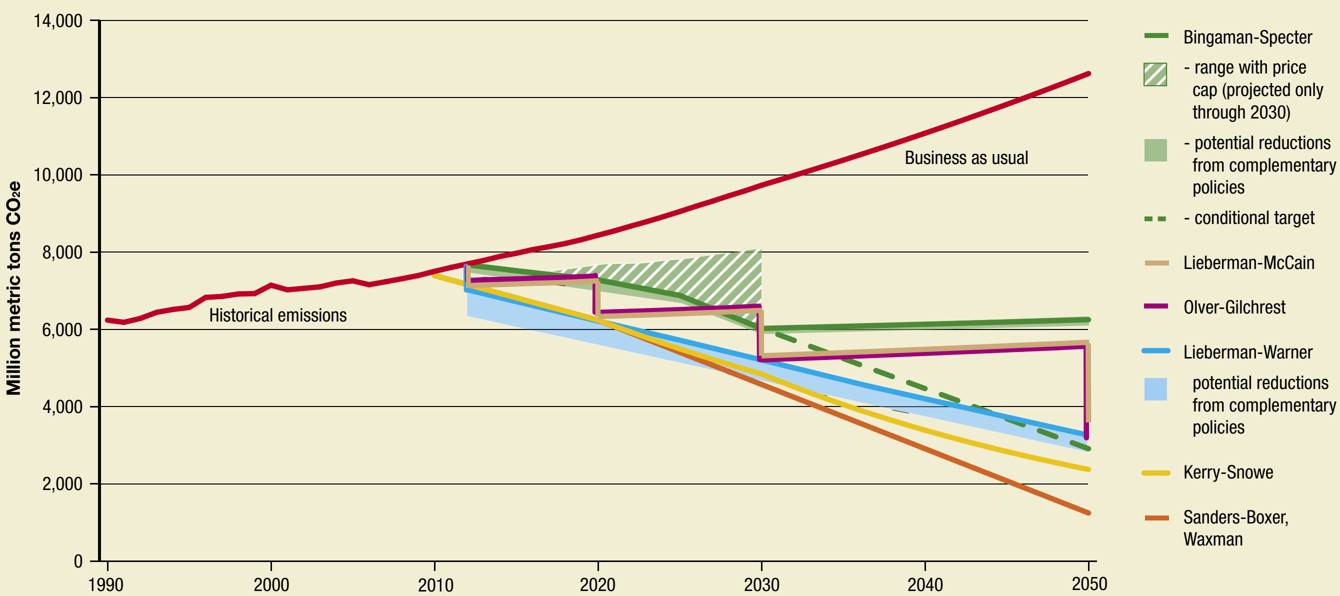
[30] Dooley, J. et al. "Carbon Dioxide Capture and Geologic Storage: A Core Element of a Global Energy Technology Strategy to Address Climate Change." 2006. Battelle Memorial Institute.

deployment. Below we discuss some of the key design elements of a cap-and-trade system and how they impact the decision to invest in carbon capture and storage.

It is clear that a sufficiently high price on carbon is only a start. A power company's capital investment decision must compare the cash outlay required for CCS with other compliance strategies under a cap-and-trade system, such as reducing emissions through increased operating efficiency or using allowances to cover a shortfall. It will also depend on whether the power industry will have to pay for the allowances or will get them handed out for free. Thus, whether CCS is actually deployed would be driven by a number of design elements of the cap-and-trade system and the structure of regional electricity markets:

- **Targets and timetables.** The price on carbon emissions is established through the emissions target or "cap." The stringency of the cap determines the supply of emissions allowances available to cover an entity's total emissions. Generally, a stringent cap with deep emissions reductions will drive a higher price of allowances.[31] In addition, the time over which emissions reductions are made is an important consideration. Policy options such as a "safety valve" that seek to provide a level of price certainty or a low cap, both of which may limit the price to less than the incremental cost of CCS technology, will likely limit CCS deployment. See Figure 8 for a set of legislative proposals and their respective targets.

Figure 8: **Comparison of Federal Legislative Climate Change Targets in the 110th Congress, 1990-2050 (December 7, 2007)**



For a full discussion of underlying methodology, assumptions and references, please see http://www.wri.org/usclimatetargets. WRI does not endorse any of these bills. This analysis is intended to fairly and accurately compare explicit carbon caps in Congressional climate proposals and uses underlying data that may differ from other analyses. Data post-2030 may be derived from extrapolation of EIA projections.

Source: World Resource Institute

[31] Demand patterns, regional growth, fuel prices, and weather variability also shape electricity output and thus CO_2 emissions. In addition, secondary market participants trading in commodity markets may also influence the supply and demand of allowances.

Box 5: A Carbon Tax

A carbon tax is an alternative policy tool for placing a price on carbon emissions. It is an excise tax on the sale of fossil fuels—coal, petroleum products, and natural gas—based on their carbon content. A tax is widely considered to be the least prescriptive approach to regulation as it does not mandate emissions reductions in any one sector. With a carbon tax, policymakers set the price of a ton of emissions and participants determine how much they will emit based on that price, whereas, a cap-and-trade program establishes the emissions limit (cap) and the market determines the price.

Since different types of fossil fuel contain different amounts of carbon per unit, a levy on carbon would place a higher tax on coal because coal has a higher carbon content per unit of thermal energy than other fuels. Although most federal and state climate change proposals focus on cap-and-trade a carbon tax cannot be completely ruled out.

- **Flexible mechanisms.** Design elements such as the availability of offsets, banking, and borrowing of allowances will also influence compliance with the cap and impact the decision to invest in CCS. Offset provisions allow investors to develop emissions reduction credits from projects that reduce emissions. Emissions reduction credits can then be certified and awarded to the owner of the project, who can sell them to sources regulated by the cap-and-trade program. Offset provisions increase the number of tradable allowances, and offering large offset incentives may reduce the price—and dilute incentive for CCS development. Offset provisions could, however, be designed to enhance the value of CCS through bonus credits.
- **Allowance allocation.** The method of allocation will impact the cash outlay required to comply with the cap. Allowances may be auctioned, grandfathered, or a combination of the two methods.[32] A decision to auction allowances imposes a cash cost to purchase allowances from the government and a higher percentage of auctioned allowances will increase cash compliance costs. Higher up-front cash costs may limit available capital for new investments, limiting CCS development. However, revenues from auctions may be devoted to subsidizing CCS capital expenditures.
- **Market structure.** To the extent firms practice marginal cost pricing, output prices rise when the price of an input increases, in this case carbon compliance costs. In deregulated electricity markets, it is likely that carbon cost will be passed through to customers (absent long-term contracts that lock-in electricity prices). The level of this increase will differ on a regional basis depending on carbon intensity of the marginal generation unit (e.g. oil, gas, coal, nuclear, or hydro). In regulated electricity markets, which practice cost of service pricing, the ability to pass through cost is much more uncertain and will depend on regulatory procedures that facilitate the timely pass through of carbon compliance costs.

Combined, these variables will drive the financial impact of a cap-and-trade system. If the net present value of a conventional coal plant, including the cost of cash outlays for cap-and-trade compliance over the life of the plant is greater than the net present value of a plant including CCS, there is no financial incentive for CCS deployment. The least-cost compliance strategy then will be to simply purchase allowances on the market. CCS is only financially feasible if the associated costs, including capital expenditures, energy penalty, increased operating costs, transport and storage, in taking the emissions liability to nearly zero (the CO_2 is sequestered therefore there are minimal emissions) is less than the cost associated with other compliance strategies. CCS costs may, of course, be reduced through government subsidies or price supports.

Market "Push"–Standards, RD&D, and Subsidies

Strategies aimed at pushing CCS technologies into the marketplace, employed alongside policies which establish a price on carbon, are critical to the CCS scale-up effort. Full scale "in the field" demonstration projects are useful for learning, as are public private partnerships which focus on reducing CCS costs and improve integration of the technologies which make up a full CCS system. Moreover, current and near-term field demonstrations are a great laboratory for developing a comprehensive regulatory framework for CCS around storage and long-term liability issues, as well as an arena for addressing public perception concerns.

[32] Federal climate change proposals reflect a variety of allocation parameters ranging from a full auction to grandfathering a large majority of allowances. Some states in the Regional Greenhouse Gas Initiative (RGGI) are sending early signals favoring a full auction (e.g. CT, ME, VT, MA).

Performance Standards

Emissions performance standards for coal-fired power plants are analogous to a technology mandate, except that they allow generators more flexibility in determining the appropriate growth strategy in a given market. Some federal cap-and-trade proposals include provisions for emissions performance standards for new electric generating units. For instance, a draft proposal by Senators Sanders and Boxer includes a provision which would establish a performance standard for electric generating units that begin operation in 2012 and operate at a unit capacity factor of at least 60 percent.[33]

There have also been discussions within Congress on amending other laws to include performance standards or mandates for new electric generating units. For example, Senator Kerry issued a proposal which would amend the Clear Air Act to limit CO_2 emissions on new coal-fired electric generating units at 285 lbs/MWh.[34] Essentially, this performance standard could only be met by plants with carbon capture and storage.

However, the stringency of these proposals is more likely to be a political "shot across the bow" rather than realistic and efficient options for encouraging CCS deployment; while they may be adopted over the longer term, it is unlikely, given the cost of implementation, and state of readiness of the technology, that they will pass in the near term. Some analysts have proposed the concept of a low-carbon portfolio standard to stimulate carbon capture and storage. The portfolio standard would encourage development of CCS by establishing a net CO_2 emission rate per kWh or create a percentage threshold of power which must be derived from low-carbon sources.

Research, Development, and Demonstration (RD&D)

Government-funded energy research and development plays a critical role in expediting solutions to difficult technical problems that markets may fail to address. For example, full scale "in the field" demonstration projects are critical for learning but involve unusually high costs and risks, making them unsuitable for private investment. In some cases, government involvement can reassure investors that might otherwise shy away from large, capital-intensive technologies that lack a proven track record. CCS demonstration projects are also critical to key storage and monitoring data requirements, without which it is virtually impossible to obtain empirical data that would help better assess long-term liability risk, and establish standards for an eventual regulatory framework.

However, despite the importance of government research, development, and demonstration in the energy sector, RD&D budgets for this sector in industrialized countries have been static or in decline in real terms over the past decade.[35] The FutureGen project in the U.S. was one example of a government and private sector partnership producing a CCS demonstration project until it was recently "restructured." FutureGen was announced in early 2003 as a $1 billion initiative to create a "revolutionary clean coal" power plant where new technologies would be demonstrated.[36] However, in January 2008 the Department of Energy cancelled funding citing high costs and difficulty in building a futuristic coal plant of this size. The demise of FutureGen is a significant blow for CCS in the U.S– federal funds for a working plant would have provided a step forward and experience with burning coal and burying the resulting CO_2 at a large scale.

The International Energy Agency argues that at least ten major demonstrations will be necessary in order to advance technological understanding, increase efficiency, and drive down costs.[37] MIT's report, *The Future of Coal*, also highlights the need for major funding efforts for technology demonstration. The report argues that the U.S. Department of Energy's Clean Coal program is "not on a path to address priority recommendations because the level of funding falls far short of what will be required in a world with significant carbon charges."[38] MIT estimates a rough cost for a ten-year program that would fulfill the demonstration program outline in its report to be approximately $5 billion.

[33] Global Warming Pollution Reduction Act (S. 309). 110th Congress, 1st Session. January 16, 2007.

[34] Clean Coal Act of 2007 (S. 1227). 110th Congress, 1st Session. April 26, 2007.

[35] Runci, Paul. "Energy R&D Investment Patterns in IEA Countries: An Update." Pacific Northwest National Laboratory/Joint Global Change Research Institute Technical Paper PNWD-3581. 2005.

[36] FutureGen Alliance, http://www.futuregenalliance.org/.

[37] International Energy Agency (IEA). *Energy Technology Perspectives: Scenarios and Strategies to 2050.* Paris: OECD/IEA. 2006.

[38] Massachusetts Institute of Technology. *The Future of Coal: Options for a Carbon-Constrained Economy.* 2007. Available online at: http://web.mit.edu/coal/.

Subsidies and Loan Guarantees

Another policy tool that could assist CCS deployment is the provision of subsidies. These could be funded through revenue recycling from carbon taxes or allowance auctions. Many of the current congressional proposals include some form of revenue recycling where revenues from allowances are redistributed for special purposes.

An example is Senator Bingaman's "Low Carbon Economy Act," which includes an innovative provision, or "bonus" incentive, that provides additional allowances for sequestered CO_2 emissions at plants over their first 10 years of operation. In effect, this redistribution of allowances to facilities which capture and sequester carbon is a subsidy for CCS development. It bridges the gap between the CO_2 allowance price set by the legislation and the value at which CCS would theoretically become an economically attractive emissions reduction strategy. Of the total allowances that would be auctioned, 8 percent would be available as bonus allowances for geological sequestration. Under Senator Bingaman's proposed program, facilities would receive an offset credit for every ton of CO_2 sequestered through CCS, as well as 3.5 bonus allowances.[39]

The "Climate Security Act" proposed by Senators Lieberman and Warner also includes a similar provision for bonus allowances. The proposal directs the Environmental Protection Agency (EPA) to take 4 percent of the allowances for years 2012 through 2030 and place them into a "Bonus Allowance Account." The EPA is then directed to allocate the allowances to firms that are using carbon capture and storage. As in the Bingaman proposal, a rate schedule is set up where the number of bonus allowances that a firm receives for injecting CO_2 underground. The "Climate Security Act" starts out at 4.5 allowances in 2012 and gradually decreases.

Other federal climate proposals include provisions to recycle revenues collected by an allowance auction and redistribute them to low-carbon technology programs. For example, "The Climate Stewardship and Innovation Act of 2007" proposed by Senators McCain and Lieberman includes a provision whereby auction revenues would be used to finance advanced technology, demonstration, and deployment. This provision sets up a technology program that would utilize a proposal process whereby the lowest bidder for a suggested level of funding would be selected in a number of climate-related technology areas, including advanced coal generation with carbon capture and storage.

While much less specific, other federal polices have been introduced which also highlight the need for funds to spur a technology program. These proposals, such as the "Global Warming Reduction Act of 2007" and "Global Warming Pollution Reduction Act" outline a mechanism to redirect funds for technology development, demonstration, and deployment but leave the specific management of the fund's disbursement to be determined by the EPA Administrator at a future date.

Loan guarantees are another instrument which may be used for deploying initial carbon capture and storage projects. Title XVII of the Energy Policy Act of 2005 authorized a Department of Energy (DOE) program which would provide federal support and facilitate financing for clean energy projects using innovative technologies. Under the loan guarantee program, the DOE was directed to provide loan guarantees for the costs of bringing innovate technologies to commercial operation which "avoid, reduce, or sequester air pollutants or anthropogenic emission of greenhouse gases" and "employ new or significantly improved technologies as compared to technologies in service in the United States at the time the guarantee is issued."[40]

In October of 2007, the DOE invited 16 project sponsors to submit applications for loan guarantees. These projects cover advanced fossil energy, industrial energy efficiency, solar energy, electricity deliver and energy reliability, hydrogen, alternative vehicles, and biomass. Two of the advanced fossil projects are integrated gasification combined cycle (IGCC) projects. Although the program does outline a category of projects that covers "Carbon capture and sequestration practices and technologies," neither of the two IGCC projects actually includes carbon capture and storage. The DOE does report that each project would allow for potential CO_2 capture in the future.

[39] A rate schedule is set which gradually reduces the bonus allowance multiplier and is phased out in 2040.

[40] Energy Policy Act of 2005. Public Law 109-58. August 8, 2005.

Regulatory Barriers and Public Acceptance[41]

Much of the discussion around CCS has focused on relative efficiencies and capital costs of capture technologies. However, making CCS economical is not the only action needed to realize a CCS wedge. Regulatory and legal considerations with respect to injection, storage, measurement, monitoring, and verification (MMV) and liability (both operational and long-term) need to be addressed to ensure that CCS projects are safe. Successful projects are crucial to build trust in the technology.

Currently, there is 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 are conducted. Sequestration will likely require new standards and increased cooperation between federal and state agencies, and there could be inefficiencies and increased costs if the current patchwork of regulations for both CO_2 transport and use are applied to CCS at scale.

In addition, the existing standards were not designed with long-term carbon sequestration in mind. While EPA's Underground Injection Control (UIC) program governs the underground injection of fluids, such as CO_2 injection for enhanced oil recovery (EOR) or disposal of CO_2, it does not have provisions to effectively address some of the specific issues related to long-term CO_2 storage at the larger volumes and higher pressures being considered for CCS at scale. Creating a clear regulatory framework will be vital to giving industry and investors more certainty about compliance requirements and costs. The flexibility of this framework will be a key component as it will need to adapt to lessons learned in the field as more experience is gained with these practices. EPA is currently working on modifying the UIC program to cover the injection of CO_2 for geologic sequestration, and plans to issue draft rules in the summer of 2008. While these rules will cover issues such as siting, permitting, and monitoring, other matters—notably property rights and long-term liability—are likely outside the scope of the UIC program, and will need to be addressed elsewhere.

Regulatory Considerations for Transport

The transport of CO_2 from capture to storage reservoir is technically established but issues around regulatory responsibility, classification of CO_2, right-of-way, and eminent domain remain. While the safety aspects of interstate pipelines constructed for transporting CO_2 fall under the jurisdiction of the Department of Transportation (DOT), there is no regulatory oversight over rates, access, and siting of CO_2 pipelines. Oversight by this agency is somewhat limited as compared to regulation by Federal Energy Regulatory Commission (FERC) over oil and natural gas pipelines. FERC presently has no legislative authority to regulate interstate CO_2. Pipeline carriers are permitted to establish pipeline rates and the Surface Transportation Board (STB) ensures that the rates charged are reasonable and nondiscriminatory.

[41] Much of the research in this section is adapted from the World Resources Institute project on Carbon Capture and Sequestration: http://carboncapture.wri.org.

The main issues around the regulation of CO_2 transport are:

- **Classification of CO_2:** One the one hand CO_2 is classified as a commodity for its use in enhanced oil recovery (EOR), while on the other hand the U.S. Supreme Court recently declared CO_2 an "air pollutant" for purposes of the federal Clean Air Act.[42] Although the focus of the ruling was on new motor vehicles, the decision has implications for CO_2 emissions from stationary sources as well. This dichotomy creates complications for one integrated interstate CO_2 pipeline network which would then have to carry a mixture of "commodity" CO_2 and "pollutant" CO_2. Without a coherent system of regulation of CO_2 as a pollutant, commodity, or some other classification developers of interstate pipelines may face numerous litigation or negotiation challenges concerning such issues as siting, pipeline access, and terms of service.
- **Eminent Domain:** CO_2 pipeline construction will require obtaining right-of-way and eminent domain for siting the pipelines. This is largely a state issue, unlike natural gas pipelines regulated by FERC which are granted eminent domain under the Natural Gas Act of 1938. Existing state eminent domain statutes need to be reviewed to determine if CO_2 meets the requirements necessary to allow the use of eminent domain authority for CO_2 pipeline construction.
- **Ownership:** If a CO_2 pipeline is constructed for the exclusive use of a single power plant for on-site CO_2 sequestration and is owned by the power plant owners, it could be considered an extension of the plant itself. In such cases CO_2 pipelines could be eligible for regulated returns on the invested capital and their costs could be recovered by the utilities in electricity rates. CO_2 pipelines could also be owned by third parties and considered a non-plant asset providing a transportation service for a fee. Cost may still be able to be recovered by the utility in rates as an operating cost, however, differences in state regulations and cost recovery mechanisms could create economic inefficiencies and affect the attractiveness of CO_2 pipelines for capital investment.

Congress has only begun to consider some of these issues. A recent proposal "Carbon Dioxide Pipeline Study Act of 2007" introduced by Senators Coleman and Salazar directs the Secretary of Energy to conduct a feasibility study related to construction and operation of plants with carbon capture and pipelines for CO_2 transport. The proposal outlines a myriad of issues that are vital to fostering the development of a CO_2 pipeline infrastructure.

Regulatory Considerations for Storage

Underground CO_2 storage has significant liability considerations, from siting and operation to long-term storage. If commercial players are to engage in a full scale CCS industry, policymakers will have to address these liability issues—in particular long-term liability—associated with geologic storage of CO_2. Some aspects may be sufficiently covered under existing legal frameworks, whereas other aspects may require new regulatory action to spur cost-effective deployment.

The establishment of large-scale sequestration reservoirs, with clearly defined property rights and liability arrangements, is essential for the successful deployment of CCS projects. Subsurface sequestration is likely to intersect with pre-existing mineral rights, water rights, and surface estate claims. Determination of who owns the underground pore space (mineral estate or the surface estate) is likely rooted in state common law on property and mineral rights, as well as state oil and gas codes. In many respects, liability derives from CO_2 migrating into lands whose property interests have not been acquired.

Subsurface injection and trespass concerns have been addressed in similar contexts through unitization (in oil and gas operations) and eminent domain. For example, unitization, joining individual tracts into one common pool, has been used for secondary oil recovery. Agreement on unitization often requires lengthy negotiations and some states require a certain percentage (50-85 percent) of owners of the common oil pool to agree before unitization can occur.[43] However, some states do not have a compulsory unitization statute, meaning that unitization is solely on a voluntary basis.

Large geological fields for injecting CO_2 could also be created by eminent domain, which is the power of the state to expropriate private property for a public use. A determination must be made first that the sequestration project serves a public good, and this designation is yet to be established for geological sequestration projects. However, the Montana state legislature proposed a bill that recognizes geological sequestration as a public use and authorizes the use of eminent domain to secure property.

[42] *Massachusetts et al. v. Environmental Protection Agency et. al.* No. 05-1120. Argued November 29, 2006 - Decided April 2, 2007.

[43] Office of Technology Assessment (OTA). *Enhanced Oil Recovery Potential in the United States.* Washington D.C. 1978.

Leakage

The most contentious set of legal liabilities is around leakage. Since CO_2 is buoyant in most geological settings, it will seek the earth's surface. Therefore, despite the fact that some reservoirs may be generally well-configured to store CO_2, there is the possibility of leakage from storage sites. Leakage of CO_2 would negate some of the benefits of sequestration and presents a number of risks. If the leak is into contained environments, CO_2 may accumulate in high enough concentrations to cause adverse health, safety, and environmental consequences. Six categories of risk from leakage have been identified:[44]

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 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 (like natural gas) with CO_2 or displaced brines.
6) General environmental degradation as in the case of Horseshoe Lake near Mammoth Mountain, California in the 1990s. The release of natural CO_2 to surface soils through volcanic fissures resulted in the death of approximately 100 acres of forest.

Experts believe these risks are manageable, and comparable to other industrial activities, if projects are properly sited, operated, and monitored.[45] However, a small percentage of sites might have significant leakage rates, which may require substantial mitigation, remediation, or even abandonment.

Long-term Liability

A final set of liabilities involves 5 long-term care and monitoring of closed sites. CO_2 is likely to remain underground for hundreds or thousands of years, therefore, determination of liability for leakage and defining responsibility to manage the CO_2 after the well has been plugged and closed is a key concern.[46] Risks to humans, water supply, and property are similar to those that exist in the operational phase, although they are likely to be less potent, because the site becomes more secure with time as the CO_2 plume stabilizes.

It is unlikely that any commercial operation would agree to assume responsibilities indefinitely. In the event of an accident or damage years after the well is closed, who is financially and legally responsible? Current law and policy is unclear on this matter, and more generally on the matter of responsibility for long-term measuring and monitoring of the site. In particular, the degree to which private parties remain responsible, or the government assumes a measure of responsibility, is important. If responsibility is transferred to the public sector, there must be sufficient public funds for managing the site over the long-term.

One approach would be for the government to assume liability for the geologically injected CO_2 at some fixed date, for example, at the end of operations or alternatively at some set date during the post-closure period.[47] Another possibility is a performance standard, which would set certain requirements to be met (e.g. stabilization of the CO_2 plume, no or low leak rates expected).

The transaction costs of these approaches should be considered. On the one hand it is necessary to clarify who will be responsible for long-term site care and for how long. On the other hand given that a large commercial CCS operation could potentially involve complex negotiations among a power producer, a pipeline company, a drilling contractor, an injection company, financiers, and insurers, specific establishment of legal responsibility could push deals to the point where transaction cost become too high, preventing completion.

Public Acceptance

While demonstration projects around the globe can help show that the CCS risks are low, public perception of such risk will be critical to the development of CCS. A pessimistic public has the potential to take the CCS option off the table and could also shape the costs of deployment if permits are difficult to obtain or permitting hurdles are high.

[44] de Figueiredo, Mark. "The Liability of Carbon Dioxide Storage." Ph.D. Thesis. MIT. 2007.

[45] IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H.C. de Coninck, M. Loos, and L.A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

[46] Most CCS related references define "long term" to be anywhere from 50 to 200 years.

[47] Full Committee Hearing on Carbon Sequestration. 110th Congress, 1st Session. (2007) (testimony of Kipp Coddington)

There are two general categories of risks—risks that are local in scope and those that are global. Local risks are those that could threaten human and ecosystem health, underground resources such as drinking water, or the structural integrity of the overlying surfaces. Above a concentration of roughly 10 percent, CO_2 can asphyxiate humans and animals. CO_2 can contaminate drinking water, either by raising PH levels or by mobilization of metals. It can also impact oil and gas resources. Another local risk relates to induced seismicity, fracturing, subsidence, or ground heave as a result of injecting pressurized CO_2. Global risks primarily relate to the release of CO_2 into the atmosphere and exacerbating climate change.

Recent surveys and studies have found that the public is not aware of carbon capture and storage as an emissions reduction option, and even fewer understand the details of the technology or the associated risks. A 2006 study by MIT found that less than 5 percent of people in the U.S. had even heard of CCS.[48] Because public knowledge of CCS is limited, media portrayal of CCS along with NGO acceptance will play a large role in shaping public perceptions about these technologies.

While many CCS experts believe the risks to be relatively low, public perception of the risks will determine whether projects can move forward without significant obstruction. A fundamental concern that will have to be overcome is the acceptability of having a CCS project near one's home, school, or office. The "not-under-my-back-yard" (NUMBY) issue often surfaces in permitting power generation projects, storage of environmental waste, etc. In addition, there is the perception that costs and risks will be borne by the local community while the benefits go to the larger global community.

Public outreach is the best tool to address public misconceptions. The DOE Regional Sequestration Partnerships (see Box 4 on page 14), which oversee 25 pilot projects throughout North America, engage the local communities near each project site and are important in this process. Their goal is to identify local concerns and develop mutually acceptable means of addressing them. To date, none of these pilot projects have been opposed.

To be really effective, however, public outreach must go beyond the affected community and engage the larger public—regional and national stakeholder groups, NGOs, public officials, and others. These groups will be active in any public debate over the costs and benefits of deploying CCS as a carbon mitigation technology and the policies necessary to ensure its safety and effectiveness. A larger public debate about actions to address climate change will also help shape attitudes about CCS. To that end, WRI is convening a stakeholder partnership of over 75 businesses, governments, NGOs, and other parties interested in CCS technologies, which has as its ultimate objective the development of best practice guidelines to ensure safe and cost-effective CCS projects (see Box 6).

Studies on public acceptability of CCS show that concerns derive primarily from uncertainty about the potential risks and the lack of a system to manage those risks. This is exacerbated by a lack of awareness and understanding of the technology, as well as insufficient engagement with the public on the development of a regulatory structure for CCS. Thus, it will be critical for policymakers to develop a comprehensive regulatory structure to manage the risks of CCS, and establish channels for the public to participate and develop confidence in the technology. In addition, actual experience with large-scale demonstration projects will help communicate to the public that the risks can be low under a well-managed system.

Box 6: The WRI CCS Initiative: On the Road to Project Standards

Initiated in 2006, the WRI CCS Initiative is a stakeholder partnership of over 75 representatives from business, government, NGOs, and academia who are paying attention to CCS. The objective of this project is to build stakeholder consensus around guidelines for the safe and effective deployment of the technology and to inform and engage the public on CCS.

The WRI guidelines are concerned with protecting human health and safety, and underground sources of drinking water and other natural resources—while facilitating cost-effective and timely deployment of CCS technologies. They will cover each phase of a CCS project lifecycle, including CO_2 capture, transport, site characterization and assessment, operations, and site closure. Publication is planned for September 2008, and when completed we hope these guidelines will serve a variety of audiences interested in best practices for CCS projects including project developers, policymakers, investors, civic groups, regulators, and the general public.

In addition, WRI has held a series of workshops on ways to address long-term liability and financial assurance. Finally, WRI has also published a series of *Issue Briefs* that highlight key issues, opportunities, and barriers for CCS. More information can be found at http://carboncapture.wri.org.

[48] Reiner, D. et al. "An International Comparison of Public Attitudes Towards Carbon Capture and Storage Technologies." 2006. Available online at: http://sequestration.mit.edu/pdf/GHGT8_Reiner.pdf.

Cost and Financing Challenges

Advanced coal technologies are more expensive than traditional pulverized coal technologies. In addition to increased capital costs, a full CCS system will have costs attached to the compression, transportation, injection, storage, and monitoring of sequestered CO_2. It is difficult to assess these costs because estimates around new coal capacity, as well as pipeline and storage capacity are extremely fluid. Still, future investments in power generating technologies must balance these carbon capture and storage expenditures with potential liabilities and increased operating costs created from policies that cap emissions.

The current premiums attached to new CCS technologies can be expected to come down as experience and scale are gained. However, construction costs for all power generating technologies are rising, with coal plant capital costs even doubling in some instances. Overall future cost trajectories will be affected by both trends.

In terms of financing an eventual clean coal build-out, the major challenge to capital formation around low-carbon technologies is that the technologies are relatively new and untested. This poses a fresh set of risks for construction firms, which may be unwilling to extend the same performance guarantees for them. Therefore, deployment of advanced coal technologies may require innovative approaches to risk and reward structures to make financiers comfortable with investing in promising new technologies. This may require, for example, exploring increased government participation.

In the following section we highlight some of the cost premiums associated with advanced coal technologies, individual costs of all components of CCS systems (advanced coal technologies, transport, and storage), and likely trajectories of how those costs may be reduced over time. We also discuss the recent escalation in power project costs, which have nearly doubled in recent years. Finally, we also look at some of the financing trends around capital spending in the power sector highlighting constraints and possible solutions to the formation of capital around low-carbon technologies.

Cost Premiums on Advanced Coal Technologies

All coal plants, from subcritical to supercritical to IGCC, can be fitted for carbon capture and storage. Although, as the 2007 MIT analysis shows (see Figure 9), the cost of adding CCS to these technologies varies significantly. Generally, adding CCS to a pulverized coal plant is estimated to be more costly then capturing emissions from an IGCC facility. Adding capture to a pulverized coal plant not only requires component parts for the actual capture system but also requires diverting a large amount of energy for flue gas capture of emissions. As Figure 9 shows, generating efficiencies drop 9-10 percentage points and additional capacity to "makeup" for the energy loss is required.

IGCC plants also require additional capital expenses for component parts in the capture process and experience an energy penalty but it is not as much—generating efficiencies drop 7 percentage points. Capturing raises costs 74 percent for subcritical, 61 percent for super-critical, 54 percent for ultra-supercritical, and 32 percent for IGCC. Therefore, while initial capital outlays are more, the MIT analysis suggests that applying carbon capture to an IGCC plant may be more economical.

Figure 9: **Comparative Cost Increases for Capture Technologies**

	Subcritical PC		Supercritical PC		Ultra-Supercritical PC		IGCC	
	W/O Capture	W/ Capture	W/O Capture	W/ Capture	W/O Capture	W/ Capture	W/O Capture	W/ Capture
Performance								
Generating Efficiency (HHV)	34.3%	25.1%	38.5%	29.3%	43.3%	43.1%	38.4%	31.2%
CO_2 emitted, kg/h	466,000	63,600	415,000	54,500	369,000	46,800	415,983	51,198
CO_2 captured at 90%, kg/h (2)	0	573,000	0	491,000	0	422,000	0	460,782
	74%		61%		54%		32%	
Costs								
Total Plant Cost $/kW (3)	1,280	2,230	1,330	2,140	1,360	2,090	1,430	1,890
Investment Charge cents/kWh	2.60	4.52	2.70	4.34	2.76	4.24	2.90	3.83
Fuel cost, cents/kWh @ $1.50/MMBtu	1.49	2.04	1.33	1.75	1.18	1.50	1.33	1.64
O&M cost, cents/kWh	0.75	1.60	0.75	1.60	0.75	1.60	0.90	1.05
COE cents/kWh	4.84	8.16	4.78	7.69	4.69	7.34	5.13	6.52

Basis: 500MW plant net output, 85% capacity factor; for IGCC, GE radiant cooled gasifier for no-capture case and GE full-quench gasifier for capture case.

(1) Efficiency = (3414 Btu/kWe -h)/(heat rate)

(2) 90% removal used for all capture cases

(3) Based on design studies done in a period of price stability between 2000 and 2004. Updated to 2005 dollars using CPI inflation rate. Current costs would be higher because of recent increses in engineering and construction costs.

(4) Does not include costs associated with transportation and injection/storage.

Source: MIT

Technology Cost Curve Trends

Costs of new technologies usually come down as experience is gained by producing and using the product. The theory that the share of the market controlled by a new technology plotted against time typically follows an S-curve is a well documented one.[49] As engineering firms learn how to construct the plants more efficiently, and as companies running the plants improve performance, there are increases in competitiveness and the rate of market penetration. Standardization and economies of scale also help to reduce unit production cost. Research suggests a 20 percent unit cost reduction for a doubling of cumulative installed capacity, an observation that is widely used to project future costs of energy technologies.[50]

However, the circumstances for CCS are somewhat different from the usual technology cost curve because, as already discussed, it is *not a single technology*, such as a scrubber or a chemical absorption system. It is a string of processes, and technological change will occur via incremental improvements to component technologies. Cost reductions of CCS systems should be calculated as the sum of all process cost reductions per level of installed capacity in capture, transport, and storage of CO_2.[51]

Capture Technology Costs

There are a multitude of factors that can influence adoption and diffusion, such as improvements in the technology itself, regulatory policy, and business cycles. In the case of capture technology the penetration rate could largely be a function of a possible carbon price, the level of that price, and other regulatory policies around storage and long-term liability.

[49] Geroski, P.A. "Models of Technology Diffusion." *Research Policy* 29. 2000: 603-625.

[50] OECD/IEA. *Prospects for CO_2 Capture and Storage.* 2004. Paris: OECD/IEA.

[51] Rubin, E. et al. "Use of Experience Curves to Estimate the Future Cost of Power Plants with CO_2 Capture." I*nternational Journal of Greenhouse Gas Control I.* 2007: 188-197.

According to the IEA, cost of capture is estimated to come down 50 percent to $25-50 per ton of CO_2 by 2030,[52] while the IPCC, estimates cost reductions of 20-30 percent in the next decade.[53] For post-combustion capture, research is being conducted to test and develop better solvents that could reduce the energy penalty. Studies suggest that solvents such as chilled ammonia may reduce power diverted for capture to as little as 10 percent.[54] For pre-combustion capture, researchers are developing membrane technologies for separating the CO_2 from syngas, which may have the potential to reduce power requirements by 50 percent.[55]

Transport and Storage Costs

While it is true that a significant portion of CCS costs are associated with capture, additional costs will be incurred for transport and storage. Transport costs will largely depend on what type of transportation system is developed. A centralized CO_2 system may develop if the CO_2 is to travel very long distances to localized geologic storage sites. A more decentralized system could also be developed if suitable sequestration sites are located in close proximity to the plant.

Another factor for consideration is who will operate and maintain the necessary CO_2 transport system. Utilities themselves could develop the pipeline infrastructure necessary to transport the carbon dioxide waste stream, in which case they would pay for the additional capital outlays for pipeline construction and development of a storage site. Or, another model could emerge whereby midstream pipeline operators construct and operate the CO_2 transport system, while long-term storage is handled by another company or a government agency with ability to bear long-term liability for storage. Under this model transport and storage costs would be an operating cost borne by the utility.

Eventually, decreases in the cost associated with transport and storage may simply be a function of scale. It is likely that initial projects will capitalize on storage opportunities in close proximity. Increased deployment may lead to a dedicated and interconnected CO_2 transport system for injection at safe and reliable sequestration sites.

Power Plant Construction Cost Trends

Engineering, procurement, and construction costs for all power plants are currently on the rise. Increasing material input costs (e.g. metals, steel, and cement), as well as labor costs, are pushing construction costs for all power plants higher. Cost estimates vary greatly throughout the industry; much depends on whether capitalized interest and soft costs are included. Many power companies will cite the "overnight cost" of a plant rather than total cost in order to minimize the figure, which is misleading.

The MIT study cited the cost of coal plants without capture in the range $1,280-1,430 per kW based on data from 2002-2004. Today, a more instructive benchmark for pulverized coal plants would be around $3,000 per kW based on recent plant announcements such as Duke Energy's Cliffside plant in North Carolina and Genpower's Longview plant in West Virginia.[56] According to a recent study, other examples of projects that have announced significant construction cost increases over the past few years include:[57]

- Westar's proposed coal plant in Kansas – originally estimated at $1 billion, increased by 20 percent to 40 percent over just 18 months.
- White Pine Energy Station in Nevada – costs more than tripled during the past two years.
- Taylor Energy Center in Florida – cancelled after its costs rose by 25 percent or $400 million, in just 17 months.

The current cycle of rising material costs and construction cost increases do not present good news for additional CCS investments. The technologies that make up a CCS system are constructed out of the same material inputs used for basic plant construction, concrete, steel, valves, and pipes. Accurate cost estimates are hard to come by given the industry's limited experience with IGCC and with applying capture technology. For a comparable "capture-ready" plant cost, Tampa Electric cancelled a planned 632 MW IGCC project in Florida at the beginning of October 2007, which was estimated to cost $2 billion or $3,165/kW.[58] Note, however, that while this includes the cost of IGCC, it does not include the cost of actual capture. A more indicative

[52] OECD/IEA. *Prospects for CO_2 Capture and Storage.* 2004. Paris: OECD/IEA.

[53] IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Summary for Policymakers. A Special Report of Working Group III. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[54] Electric Power Research Institute (EPRI). "Pathways to Sustainable Power in a Carbon-Constrained Future." *EPRI Journal.* Fall 2007.

[55] Electric Power Research Institute (EPRI). "Pathways to Sustainable Power in a Carbon-Constrained Future." *EPRI Journal.* Fall 2007.

[56] The Cliffside plant is an 800 MW supercritical pulverized coal facility estimated to cost $2.4 billion as referenced in Duke's 2007 10-K and includes both construction and financing costs. The Longview plant is a 695 MW supercritical pulverized coal plant estimated to cost $1.82 billion.

[57] Schlissel, David et al. "Don't Get Burned: the Risk of Investing in New Coal-fired Facilities." Interfaith Center on Corporate Responsibility. February 2008.

[58] Tampa Electric. Available online at: http://www.tampaelectric.com/news/article/index.cfm?article=423.

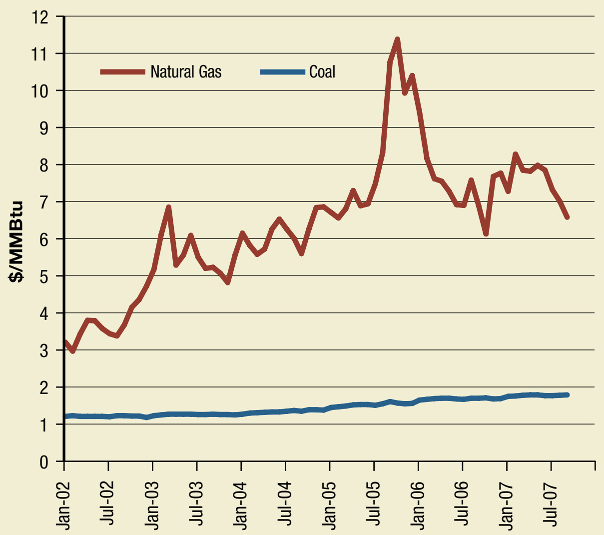
cost may be the recently restructured FutureGen project, which had seen its costs nearly double to $1.8 billion for a 275 MW plant, or $6,500/kW.

Box 7: Rising Operating Costs

Operating costs are also increasing because fuel prices (the biggest component of operations and maintenance) are rising. Fuel costs will have a relatively larger effect on a coal plant that captures CO_2 due to the energy penalty and additional plant capacity requirements, which increases fuel consumption.

One piece of positive news, however, is the relative price of coal versus the price of oil and gas. MIT, for instance, believes that coal-based technologies with sequestration will penetrate, despite their higher cost today, because of projected rising natural gas prices.[59] This may become an important part of the discussion as natural gas is likely to be a big player in the U.S. while CCS technology is developing.

Fuel Costs for Electricity Generation



Source: Energy Information Administration, Electric Power Monthly

The Financing Challenge

Independent of the cost trajectories of CCS technologies, significant capital will be required for a scaled-up deployment of low-carbon power generation. Despite the current excitement over CCS as a solution for the continued use of coal, there are significant financing difficulties around an eventual clean coal build-out to the scale that is required.

Investors and financiers are increasingly aware of the issues surrounding coal plants, and weary of investing capital in new plants that are not considered environmentally clean. Caution around new coal-fired power plants built without new technology—that is, without the capacity to capture greenhouse gas emissions—is rising on Wall Street. Pressure on major banks to begin weighing climate policy risk when deciding whether to finance new plants, should be good news for CCS on the face of it. But banks have not indicated what they will finance instead of dirty coal: will it be IGCC, renewable energy, or nuclear power?

Two developments are indicative of this trend. First, the private equity led buyout of the Texas utility TXU, in which eight of eleven proposed coal plants were rejected, clearly highlighted that capital markets now largely factor in a "carbon constrained economy," and are integrating potential climate change policies into investment decisions.

Second, in February 2008 three major investment banks—Citi, JPMorgan Chase, and Morgan Stanley—announced new environmental guidelines. The *Carbon Principles* present an enhanced due diligence process for companies seeking financing for new fossil fuel generation in the United States.[60] Through these guidelines the banks will encourage clients to pursue cost effective energy efficiency, renewable energy, and other low carbon alternatives to conventional generation. The banks also commit to analyzing the financial risk posed by the prospect of domestic climate policy. While the significance of the *Carbon Principles* should not be over-interpreted – they are essentially guidelines that do not in any way constitute industry standards – they are nevertheless a harbinger of things to come. Wall Street's new carbon screen is a material development in that it will add an additional level of scrutiny.

[59] MIT. The Future of Coal: Options for a Carbon Constrained Economy. 2007. Available online at: http://web.mit.edu/coal/

[60] www.carbonprinciples.org

Box 8: "Capture Ready" Investing

There has been considerable debate recently regarding whether new coal power plants should be "capture ready" and an equal amount of controversy on what exactly is required for "capture readiness." According to MIT, making power plants capture-ready entails making it cheaper to later fit the plant with a CCS system. This is done by making investments during the design and construction phase that accommodates an eventual retrofit. It also includes ensuring that there is sufficient space to construct the necessary capture facilities and outlining sequestration issues.

The International Energy Agency (IEA) GHG Programme proposes that the aim of building plants that are capture ready is to reduce the risk of stranded assets or "carbon lock-in." This definition goes further and gives examples of what needs to be considered and included—sufficient space for the capture equipment, access to the additional facilities, and reasonable routes to storage sites. Other definitions include technical specifications such as a low-sulphur content in the gas stream. The notion of "capture ready facilities" adds another level of complexity. A "capture ready" plant may not be worth much without a parallel "capture ready" transport and storage system. Capturing CO_2 makes little sense without suitable sequestration sites which have addressed the legal and regulatory issues associated with geological storage of CO_2.

This Paper suggests that a working definition of "capture readiness" should cover all system parts for capture readiness—design and construction elements of the plant itself as well as elements of the transport and storage facilities and define the full range of technical options a plant or a facility has to have in order to be considered ready. Regardless of the ultimate definition, the issue is that no power company is likely to be willing to build so called "capture ready" plants and make investments today in what could become expensive assets in the absence of *future* carbon regulation. Requirements that new plants be built "capture ready"—designed with additional room to install capture technology at a later date—is unlikely to help guide investment decisions of companies considering new power project today.

Furthermore, the current capture ready discussion does not inform the debate on how to handle existing plants and whether they should be retired or retrofitted. Retrofitting a conventional coal-fired plant optimized to operate without CCS will require process changes and major technical modifications to fundamental operating components such as turbines, heat rates, and gas clean up systems, which may end up costing more than building a new plant if the existing plant is due to be retired within a short timeframe.

Ability of Power Companies to Raise Capital

A discussion of capital formation around CCS technologies cannot happen in a vacuum; it must also consider the current environment of power sector financing in general. Cambridge Energy Research Associates estimates that $900 billion of direct infrastructure investment will be required by electric utilities over the next 15 years which compares to the $750 billion currently in place.[61] New investors have entered the space as private equity funds, infrastructure funds, pension funds and hedge funds all now provide capital to the sector. U.S. investment banks are now invested in the sector both as owners and lenders.

Coal-fired plants can be built by a number of different entities, including investor owned utilities, public power initiatives, and independent power producers (IPP). How the capital investments would be financed will be differentiated among these players. Large investor owned utilities may be able to channel cash from their balance sheet into new projects or raise money in the capital markets. However, recent trends and future projections suggest that free cash flow available for electricity utilities to fund capital expenditures may be limited and insufficient to cover current levels of capital expenditures.[62]

IPPs may be more likely to seek project financing—in other words to finance power projects as distinct independent projects which are off the balance sheet of the company. Some firms are also considering financial partners, private equity, or joint ventures as ways to lower the cost of capital. Escalating construction costs are also having an impact on the ability of power companies to raise financing. In such an environment it is even harder for project developers to prove to state regulators that lower-carbon technologies, particularly IGCC, are a least cost resource.

Lack of Technology Performance Guarantees

A scaled-up deployment of any new technology requires financial structures that will help mitigate certain risks and bring the technology into the market place. A cost on carbon emissions will go a long way to make investments in emission control technologies more attractive, but government assistance in bearing some of the risks will be needed to drive further investment.

A primary risk that must be addressed in building a new power plant is construction risk—the risk that the plant is delivered on schedule, on budget, and initially operating up to the agreed upon thermal and environmental performance specifications.

[61] Wood, Roger. "Banking on the Big Build." *Public Utilities Fortnightly.* October 2007.

[62] Wood, Roger. "Banking on the Big Build." *Public Utilities Fortnightly.* October 2007.

In the electricity sector plant owners generally hire Engineering, Procurement, and Construction (EPC) companies to design and build power plants and look to these firms to provide contractual guarantees (EPC wraps) to assure the plant will be built and initially operate as expected.

As part of these guarantees, power plant owners may seek provisions for liquidated damages if the EPC firm does not deliver on its contractual obligations. Liquidated damages are generally expressed as a percentage of project capital cost and tend to be on the order of 10 to 15 percent for pulverized coal and natural gas combined cycle power plants for which costs and risks are relatively well known.

However, with increased demand for infrastructure projects it is becoming difficult to secure performance guarantees for power infrastructure. Relatively new and unproven baseload power generation technologies like IGCC pose additional difficulties. EPC firms have indicated a reluctance to enter into IGCC contracts which would hold them liable for damages for failure to deliver a completed plant by a stated date that meets stated requirements. A similar situation could develop related to CSS, particularly because the capture process requires diverting large amounts of energy, and could be an issue for initial full-scale CCS projects.

But these contractual provisions are critical for both lenders who are repaid out of the cash flows generated by the project and for equity investors for whom, without the debt financing, the projects carry an unacceptable amount of high risk equity. They provide a form of insurance for both lenders and equity investors. Lack of EPC wraps is a major constraint on willingness to finance low-carbon power generation plants, in particular for the early plants. As a track record is established, this will be less of a problem, as there will be increased willingness to extend performance guarantees.

Lack of Liability Insurance for Long-term Storage

Financiers must have assurances that developers and operators of CCS projects have the means to construct, operate, and close their carbon sequestration facilities in an environmentally sound manner. It is very important to ascertain risks properly; if risk is under or over-estimated the financial instruments chosen to hedge against that risk will be sub-optimal. Financial responsibility starts with risk management and a clearly defined risk profile that asks the following questions:[63]

- What is the nature of the risk?
- What is the timing and probability of risk?
- How might the risk(s) be ranked or prioritized?
- Which risks bear managing, and by whom?

Several risk management models currently exist to address public environmental risk in other areas, some of which may be applied to CCS. In the U.S., the Resource Conservation and Recovery Act (RCRA), mandates by law that standards be established addressing financial responsibility, as such standards may be necessary to protect human health and the environment. The RCRA model requires companies to set aside funds for post-closure care of solid or hazardous waste sites, but also offers them third-party instruments such as trust funds, letters of credit and insurance, as well as self-insurance instruments such as the corporate guarantee.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), often referred to as Superfund, established a tax to finance a fund that addressed liabilities arising from clean up of hazardous waste sites. Specifically, it provided for a cap on clean up costs where contamination costs are greater than estimated. One of the strengths of this approach is its flexibility and the fact that it allows for tailored risk management products.

A federal insurance program to indemnify project developers and operators may be appropriate to address long-lived liabilities occurring during the post-injection phase of CO_2 sequestration. Insurance instruments are designed to pool risk and encourage technological advances. An example is the Price-Anderson Nuclear Industries Act, one of the most well-known federal insurance models, which is designed to protect the nuclear industry for liabilities arising from accidents.

Others believe that any federal indemnity program should be limited, as the public should not be subsidizing private development and implementation of CCS technologies indefinitely. The issue of designing an effective financial responsibility framework is a critical one. It should create incentives for best practices at each phase of a project lifecycle, while facilitating the growth of a nascent industry that may need some assurances that potential liabilities are not excessive.

[63] Wilson, Elizabeth J. et. al. "Liability and Financial Responsibility Frameworks for Carbon Capture and Sequestration." *World Resources Institute.* December 2007.

Conclusion

Coal is cheap and abundant in the United States. It is undeniable that coal is, and will remain, the major fuel source for base-load power in the U.S. for the foreseeable future. Therefore, any attempt to make coal-powered electricity generation more climate friendly through consideration of "clean" technologies such as CCS has significant value. However, the economic challenge of constructing a significant carbon capture and sequestration industry in a timeframe to slow global climate change currently overwhelms its promise:

- First, CCS will always be a cost-plus exercise where significant political will is required. CCS deployment will be a function of how policy impacts the power producers' cash flows and in turn how this impacts their least cost compliance strategies. The current policy discussion does not rise to the challenge; a carbon price alone is likely insufficient. If CCS is only one compliance strategy among other options, capital will be deployed to the least cost-compliance option.

- Second, scale is a major issue. CCS is a complex system of separate and individual processes that need to be installed and operated to capture, compress, transport, inject, and store CO_2. Meanwhile the quantities of CO_2 involved are enormous. So much supporting infrastructure in the form of dedicated transport pipes and sequestration facilities would be needed that deploying CCS systems at "wedge" scale amounts to a transformation of our entire energy infrastructure. The likelihood of such a transformation taking place in less than a few decades, without aggressive policy shifts not yet evidently forthcoming, is slim.

- Third, there are significant liability issues throughout the CCS value chain, in particular around leakage and long-term storage of CO_2. Commercial players are unlikely to engage until government provides a comprehensive legal and regulatory framework applicable to the transport and storage of CO_2. While the government could choose to absorb these risks, full and accurate quantification of such risks and the establishment of standards for a regulatory framework (including site selection, operations and post-closure rules, as well as monitoring and reporting), will be virtually impossible to set until actual CCS projects are on the ground.

- Finally, raising capital for CCS is a challenge due to the risk premiums attached to advanced low-carbon technologies, which are new to the market place. As long as construction firms have no experience with building and operating IGCC plants or other CCS systems, the lack of EPC wraps will continue to be a major obstacle to financiers. Deployment of CCS at scale will require some other financial structure, or government guarantees to investors to cover the possibility that plants do not get built on time or that they do not make a return on their capital.

WRI concludes that a shift to a low-carbon energy future in the U.S. underpinned by an economically viable national CCS system is possible, but that such a fundamental shift will likely only occur once definitive policies and incentives are put in place that reward investment in and capital formation around improved carbon performance.

While no country has yet grasped in its policy the magnitude of change that any climate "wedge," including CCS, will demand, the U.S. in particular shows a significant gap between rhetoric and action. Despite regular references to CCS in public discourse, the demise of the FutureGen demonstration project in early 2008 implies a different reality. It implies that CCS is still viewed as a painless option, to be overlaid on an essentially business-as-usual development of the energy sector.

This report suggests that as long as this attitude persists, there is little prospect of achieving a "wedge" of emissions reductions through CCS. For there to be any such prospect, U.S. climate policy support will need to be ramped up—and swiftly. This will likely require not only a carbon price significantly higher than that in the European Union Emission Trading System today, but also early demonstration support to help overcome investor concern regarding technology performance risk. Above all, CCS needs to be understood as a systems approach, in which other factors such as siting questions, rules for liability, and the building of an infrastructure for CO_2 transportation and storage will need separate but urgent attention.

We recognize that the challenge of climate change is a complex one, and no solution to reducing emissions is without significant constraints. Stabilizing atmospheric concentrations of GHGs to meaningful levels requires pursuing a range of technology options deployed in concert, and CCS may well turn out to be an important part of the solution. To determine that, however, requires a more far-reaching and urgent set of activities from both the public and private sectors than is currently the case.

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