Sustainability Watch

Carbon Capture & Sequestration

Updated
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Stimulus Package Enourages Carbon Capture & Sequestration

Watch List

- Carbon capture and sequestration (CCS) extracts CO2 from power plant emissions in order to compress the CO2 into a near-liquid form, transport it through a pipeline, and inject it into an underground geologic formation.
- The US stimulus bill of February 2009 set aside $1.5 billion for CCS research, $800 million to support the US Department of Energy (DOE)'s Clean Coal Power Initiative, and $70 million for geologic carbon sequestration research.
- In February 2009, DOE announced that up to $24 million in funding is available for carbon sequestration projects.
- In July 2009, Senators Bob Casey and Mike Enzi introduced S. 1502: the Carbon Storage Stewardship Trust Fund Act of 2009, which would manage the legal and financial risks of the long-term storage of carbon dioxide (CO2)
- In late 2010 or early 2011, the US Environmental Protection Agency (EPA) will be releasing the final version of its Class VI regulations for geologic sequestration.
- The UK announced plans to require all coal-fired power plants to reduce carbon emissions to zero by 2025. All new coal-fired power stations must capture at least 25% of carbon emissions on startup.

Related Sustainability Watch Reports

- Carbon Cap and Trade
- Carbon Markets and Trading
- Carbon Offsets

Key Takeaways

- Coal is the single-largest contributing fuel source to global CO2 emissions. CCS technology is an attractive option in the US, where coal-fired power plants provide half of US electricity and renewable energy provides just 4%.
- The components of CCS have already been successfully demonstrated – CO2 capture technology exists for ammonia production, oil refining and gas processing.
- Integrated Gasification Combined Cycle (IGCC) power plants, which produce electricity by gasifying coal instead of burning it, are more efficient and less expensive to convert to CCS than traditional coal-fired plants; however, they are significantly more expensive to build.
- Carbon captured from power plants can be used in enhanced oil recovery (EOR) efforts. EOR technologies may provide the potential to recover 43 billion barrels of oil in the US – almost double the current proven US oil reserves (DOE, 2008).
- The concept of "clean coal" has existed for decades, focusing mainly on reducing the pollutants that lead to acid rain. In the last ten years, the term has become synonymous with CCS technology.
- At this time, there is no commercial-scale coal-fired CCS power plant in operation. Several pilot programs have been initiated and a large-scale natural gas plant in Norway has been using CCS technology for over a decade.
- While there are a number of barriers to the adoption of CCS technology, including an uncertain regulatory climate, leakage concerns and long-term liability and ownership issues, the greatest barrier is cost.

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Executive Summary

Coal contributes more to CO2 emissions than any other fuel source, making up more than 40% of all carbon emissions. With coal-fired power plants providing half of US electricity, carbon capture and sequestration (CCS) is seen as a potential bridge technology between coal-based power and newer technologies that do not rely on fossil fuel consumption. In CCS technology, CO2 is separated from the flue gas emitted by power plants, compressed into a near-liquid form, transported through pipelines and injected into underground geologic formations. The components of CCS – carbon capture, transportation and underground injection – have already been successfully demonstrated. The challenge is applying these technologies to coal-fired power plants.

Three technologies are being pursued for carbon capture and removal, two of which can be retrofitted to existing pulverized coal power plants – post-combustion and oxyfuel. Pre-combustion technologies are being developed for a new kind of coal power plant, an integrated gasification combined cycle (IGCC) plant. An IGCC plant gasifies coal rather than burning it, turning it into hydrogen and carbon monoxide. The hydrogen can be used to power the combined cycle plant, as in a natural gas plant, and the carbon monoxide, because it is so concentrated, can be more effectively and less expensively captured and stored.

Once carbon is captured, it can be stored permanently in a geologic formation or injected into oil or gas reservoirs to boost production. Enhanced oil recovery (EOR) is a technology that has been performed for decades and has the potential to allow an additional 30-60% of the reservoir's original oil to be extracted. If CO2 is not used in EOR, it can be injected into underground geologic formations and sequestered underground. The DOE has created seven Regional Carbon Sequestration Partnerships to research and develop carbon sequestration technologies, with the goal of creating a commercially viable model for long-term underground CO2 storage.

In addition to its investments in carbon sequestration, the US government has funded more than $2.5 billion in clean coal technology projects since 2001. The concept of "clean coal" has evolved over the years and has now come to be synonymous with CCS technology. The DOE's Clean Coal Power Initiative (CCPI), a ten-year, $2 billion program, is focused on accelerating commercial development of advanced clean coal technologies. The future of the FutureGen Clean Coal Project, a $1billion public-private partnership to create the first IGCC power plant with CCS technology, is unclear after incorrectly calculated cost overruns put the project on hold.

Coal Fired Plant Getty 2007

At this point, there is no commercial-scale, CCS coal-fired power plant in operation. The cost for such a plant is estimated at $1 billion to $1.8 billion. Other barriers to CCS technology are leakage concerns, which could have both localized environmental effects, as well as global environmental and economic impacts. Additionally, issues concerning long-term liability and ownership of stored CO2 are still to be resolved. One of the greatest criticisms of CCS technology is that the research and development spent on it would be better spent on renewable energies.

Business Options & Best Practices

CO_2 emissions resulting from human activity have grown from an insignificant level two centuries ago to over 31 billion tons a year worldwide. According to the International Energy Agency (IEA), growth in global energy demand will lead to a 57% rise in worldwide CO_2 emissions by 2030 to 7.6 billion metric tons. These emissions would equal approximately 50% of all fossil fuel emissions over the past 250 years combined. Coal, the single-largest contributing fuel source to global CO_2 emissions, makes up 40% of all such emissions. Coal-fired power plants provide approximately half of US electricity, 70% of India's and 80% of China's. With renewable energy, such as wind and solar, making up just 4% of US electricity generation, researchers have begun to look at other methods of reducing our carbon output.

CCS is seen as a bridge technology between coal-based power and newer technologies that do not rely on fossil fuel consumption. In CCS technology, CO_2 is separated from the flue gas emitted by power plants, compressed into a near-liquid form, transported through pipelines and injected into underground geologic formations. The components of CCS have already been successfully demonstrated in ammonia production, oil refining and gas processing. Carbon has also been transported through pipelines and injected underground for enhanced oil recovery (EOR) efforts over the last few decades. According to the Intergovernmental Panel on Climate Change (IPCC), CCS has the potential to supply 15-55% of the emissions reductions necessary to stabilize CO_2 levels by 2100.

Large stationary sources of CO_2 make excellent candidates for CCS, where small sources such as vehicles or heating systems would not, because the CO_2 is too dispersed.The focus of CCS research has been primarily on coal-fueled power plants, although CO_2 could be collected from gas-fired plants as well as iron, steel and chemical processing plants and oil refineries.

Carbon Capture Technologies

Current technologies exist for separating and capturing CO_2 and are routinely performed to produce ammonia, hydrogen and beverage carbonation. Carbon capture is also being done on a commercial scale at a handful of natural gas power plants. The next challenge is the application of carbon capture technology to coal-fired power plants. Because coal-fired plants make up such a large portion of global CO_2 emissions, there is great interest in reducing these emissions. In a traditional pulverized coal power plant (PCPP), coal is crushed into a fine powder and burned in a boiler to make heat. The PCPP emits a flue gas that is made up of only 10-13% CO_2. This low concentration/low pressure CO_2 is more difficult and expensive to remove than a high concentration/high pressure CO_2, like that emitted by ammonia plants, which release more than 80% CO_2.

There are three different types of technologies being developed to address carbon capture for power plants. At this point, no one technology has emerged as the industry leader. Pre-combustion and oxyfuel technologies can be retrofitted to work with existing PCPPs. Pre-combustion technologies only work with newly constructed integrated gasification combined cycle (IGCC) plants.

- Post-combustion. This technology involves the chemical stripping or scrubbing of CO_2 after the combustion of the fossil fuel. Post-combustion technologies under development include: Chilled and non-chilled ammonia, solvents, and advanced amine systems. Post-combustion technology can be retrofitted to traditional PCPPs; however, it is expensive. Companies working on post-combustion technologies include: Powerspan Corp., with its ECO2 process; Siemens; Mitsubishi; Fluor, with its Economine FG Plus amine process; and Alstom, with a chilled ammonia process.

- Pre-combustion. In pre-combustion technology, the coal is not burned, as in a PCPP; rather, it is gasified to produce hydrogen and carbon monoxide. The carbon monoxide is removed prior to combustion and can be sequestered underground, and the hydrogen is used to fuel the power plant. Pre-combustion technology can be retrofitted to natural gas power plants or used on newly constructed IGCC coal plants. They cannot be retrofitted to traditional PCPPs. Siemens and E.ON of Germany are working on a pre-combustion technology partnership.
- Oxyfuel. This technology involves burning coal in a nearly pure oxygen environment, which eliminates nitrogen emissions, creating concentrated exhaust of CO2 and water vapor. Because it is more concentrated, the CO2 is easier to separate out, and is either absorbed using solvents or absorbed onto membranes. Oxyfuel technology can be used to retrofit existing plants, which would need to be outfitted with an all-oxygen boiler. Companies working on oxyfuel technologies include: Babcock Power Inc., ThermoEnergy Corp., Praxair, Air Products, and most major boiler OEMs.

"Air capture" technology is an emerging carbon capture technology that collects CO2 from ambient air rather than a polluting source. Such technology already exists on board submarines and spacecraft, which "scrub" CO2 from the air. The advantage of air capture is that it can be done anywhere, not just at power stations. An air capture plant could be constructed in an unpopulated area near a geologic storage site, eliminating the need for CO2 pipelines. The plant would be able to capture emissions caused by cars and aircraft, in addition to stationary pollutants. Developers must ensure that air capture plants do not cause more CO2 emissions in their own operations than they will capture.

Integrated Gasification Combined Cycle

The pre-combustion carbon capture technology described above is dependent on a new type of coal-fired power plant: An Integrated Gasification Combined Cycle (IGCC) plant. In an IGCC plant, the coal is not burned directly, but rather gasified – exposed to steam and oxygen under high temperatures and pressures. This gasification causes the molecules in coal to break apart into carbon monoxide, hydrogen and other gaseous compounds. The IGCC plant produces syngas, a synthetic gas, which is then fired in a gas turbine. The hot exhaust from the gas turbine is combined with heat from the gasification process and used to generate steam in a steam turbine-generator. This "combined cycle," or dual source of electric power, is able to put the coal to use in a more efficient way than a traditional PCPP. It also produces a concentrated, high-pressure stream of carbon monoxide, which can be more easily captured and sequestered. This pre-combustion carbon capture is much less expensive to perform than the post-combustion carbon capture of a traditional PCPP.

Because they are more efficient than PCPPs, and because of the potential to more easily and less expensively remove carbon from their exhaust, IGCC plants are an attractive option from an environmental perspective. IGCC plants are, however, 30% more expensive to build than PCPPs. The cost of electricity production for CCS would increase by 35% for IGCC plants and by 77% for PCPPs. The average price of electricity in the US is 8.9 cents/kilowatt hour. Retrofitting an existing PCPP to capture 90% of CO2 emissions would increase the cost by nearly 7 cents/kilowatt hour.

Enhanced Oil Recovery (EOR)

Once carbon has been captured from a power plant, it can either be sequestered in an underground geologic formation, or injected into an oil or gas reservoir to boost flagging production. Where carbon sequestration in underground geologic formation is currently being tested through pilot programs, its injection into oil reservoirs for enhanced oil recovery (EOR) has been successfully performed for decades. Using OER technology, the CO2 is piped to an oil reservoir and injected into the oil-bearing stratum at high pressure. The CO2 displaces the oil, allowing an additional 30-60% of the reservoir's original oil to be extracted. When CO2 is used in EOR, about half of it can be recycled for future use, while the remainder is permanently stored in the geologic formation. Currently, over 50 million tons of CO2 are injected underground in the US in EOR activities. This quantity is the equivalent to the amount of CO2 estimated to be captured annually from the first 20 newly constructed 500-MW CCS plants.

The DOE estimates that EOR technologies may provide the potential to recover 43 billion barrels of oil in the US. In comparison, the current proven oil re serves in the US account for 28 billion barrels. Given oil prices of $150 per barrel, the value of this addi tional recovered oil would be approximately $6 tril lion. These potential benefits show how EOR can turn carbon sequestration into an investment, rather than a cost, with CO2 a commodity rather than a pollutant.

Geologic Sequestration

If CO2 is not used in EOR, it can be injected into underground geologic formations and sequestered under ground. The DOE and IEA estimate that the US alone has the capacity to store over 3 trillion tons of CO2 in underground geologic formations – the equivalent of 1,000 years of emissions from 1,000 coal plants. The DOE is currently looking at five types of geologic formation for CCS:

- oil and natural gas reservoirs
- deep unmineable coal seams
- deep saline formations
- oil- and gas-rich organic shales
- basalt formations

Injecting CO2 into oil and natural gas reservoirs and coal seams has the potential to increase their production, as outlined above. Saline formations

	DOE estimate of North American CO2 storage capacity (billion metric tonnes)	Years of current total US CO2 emissions from power plants that could be stored
Mature Oil and Gas Reservoirs	82	33 years
Deep Umineable Coal Seams	156-184	63-74 years
Deep Saline Aquifers	919-3,378	371 to 1,364 years
Total	1,158-3,644	

Marston, P., & Moore, P. (2008, November). FROM EOR TO CCS: THE EVOLVING LEGAL AND REGULATORY FRAMEWORK FOR CARBON CAPTURE AND STORAGE. (Italian). Energy Law Journal, 29(2), 421-490. Retrieved May 11, 2009, from Business Source Complete database.

do not offer the same value-added feature, but do have the advantage of being located near coal sources, which would eliminate the need for extensive piping of carbon. Saline formations also offer greater volume than the first two options.

In order to research and develop carbon sequestration technologies, infrastructure and regulations, the DOE has created a network of seven Regional Carbon Sequestration Partnerships (RCSP). The seven partnerships are:

Regional Partnership	Lead Organization	Member States/Provinces	Website
Big Sky Carbon Sequestration Partnership (BSCSP)	Montana State University	MT, ID, SD, WY, Eastern OR and WA, and adjacent areas in British Columbia and Alberta	www.bigskyco2.org
Midwest Geological Sequestration Consortium (MGSC)	Illinois State Geological Survey	IL, western IN, western KY	www.sequestration.org
Midwest Regional Carbon Sequestration Partnership (MRCSP)	Battelle Memorial Institute	Easter IN, eastern KY, MD, MI, NY, OH, PA and WV	www.mrcsp.org
Plains CO2 Reduction (PCOR)	Partnership University of North Dakota, Energy and Environmental Research Center	eastern MT, eastern WY, NE, eastern SD, ND, MN, WI, IA, MO, Alberta, Saskatchewan, Manitoba, and northeastern British Columbia	www.undeerc.org/PCOR
Southeast Regional Carbon Sequestration Partnership (SECARB)	Southern States Energy Board	east TX, AK, LA, MS, AL, TN, FL, GA, SC, NC, VA	www.secarbon.org
Southwest Regional Partnership (SWP)	New Mexico Institute of Mining and Technology	west TX, OK, KS, CO, UT and eastern AZ	www.southwestcarbonpartnership.org
West Coast Regional Carbon Sequestration Partnership (WESTCARB)	California Energy Commission	AK, western AZ, western British Columbia, CA, HI NV, western OR and western WA	www.westcarb.org

(Reference: Carbon Sequestration Atlas of the United States of America and Canada. (2008). US Department of Energy. Retrieved May 15, 2009, from http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/2008%20ATLAS_Introduction.pdf)

The Regional Partnerships' Initiative has three phases:

- Characterization Phase I (2003-2005): Assess the potential for CO2 storage in deep oil, gas and saline-bearing formations.
- Validation Phase II (2005-2009): Implement a portfolio of 25 small-scale geologic sequestration projects, to validate and investigate the effectiveness of the technology.
- Development Phase III (2008-2018): Implement seven large-scale sequestration projects in the US and Canada.

The RCPS Initiatives are now in Phase III, with seven large-scale sequestration projects underway in the United States and Canada. The projects are:

RCSP	Project Title	Geologic Formation	Depth (Ft)	Source of CO2	Volume to Inject (tons/yr)	Total Amount CO2 Injected (metric tons)
BSCSP	Large Volume Injection to Assess Commercial Scale Geological Sequestration in Saline Formations	Nugget Sandstone	11,000	Helium and Natural Gas Processing Plant	1,000,000	2,700,000
MGSC	Illinois Basin – Decatur Project	Mt. Simon Sandstone	5,000-7,000	Ethanol Plant	365,000	1,000,000
MRCSP	Large Volume injection of CO	Mt. Simon Sandstone	3,000-3,600	Ethanol Plant	250,000	1,000,000
PCOR	Williston Basin CO2 Sequestration and EOR	Deep depleted oil fields in the Williston Basin, carbonate rocks	12,000	Post Combustion Capture Facility	1,000,000	5,000,000
SECARB	Development Phase Saline Formation Demonstration - Cranfield	Sandstones of the lower Tuscaloosa Formation	10,5000	Natural Source	1,000,000 for early test	1,500,000
SECARB	Development Phase Saline Formation Demonstration - Anthroprogenic	Tuscaloosa Formation Massive Sand Unit	9,5000	Post Combustion Capture Facility	100,000 to 250,000	At least 400,000
SWP	Farnham Dome Deep Saline Deployment Project	Deep triassic, jurrassic, and permian aged sandstones	5,000+	Natural Source	1,000,000	2,900,000
WESTCARB	Sequestration of CO2 from OxyFuel Combustion Unit, Kern County, CA	A San Joaquin Basin sandstone formation	7,000+	Oxycombustion Power Plant	250,000	1,000,000

(Reference: Carbon Sequestration Atlas of the United States of America and Canada. (2008). US Department of Energy. Retrieved May 15, 2009, from http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/2008%20ATLAS_Introduction.pdf)

The RCSPs have also provided information to the National Carbon Sequestration Database and Geographical Information System (www.natcarb.com), a geographic information mapping system (GIS) that allows users to display both carbon sources as well as potential sequestration sites. It is a digital spatial database that allows users to view the amounts of CO2 emitted by power plants, refineries, and other industries in relation to potential geologic formation storage sites.

US Clean Coal Initiatives

Since 2001, the US government has invested more than $2.5 billion on clean coal technology research and development. The concept of "clean coal" has existed for decades, first emerging before World War II when it referred to the smokeless coal preferred for home heating and cooking. During the 1960s through the 1990s, clean coal technology was focused on reducing the sulfur and nitrous oxide pollutants that caused acid rain. Clean coal has now come to be synonymous with CCS technology.

The DOE funds and oversees a number of programs focused on clean coal technology. The Clean Coal Power Initiative (CCPI) is the only active program at this time. The CCPI, a ten-year, $2 billion program, was established in 2001 to implement President Bush's policy recommendation to increase investments in clean coal technology. It is implemented through a series of five solicitations to accelerate commercial development of advanced clean coal technologies. Two solicitations have already been made; the Round 3 Funding Opportunity was released on August 11, 2008. The focus of this third round is CCS technologies. The DOE also supported two programs, which have now concluded: The Power Plant Improvement Initiative (PPII), focused on retrofitting existing power plants with clean coal technology and which completed its fourth and final project, and the Clean Coal Demonstration Program (CCTDP), with 33 completed demonstration projects focused primarily on combating acid rain.

The DOE is also responsible for funding the FutureGen Clean Coal Project. FutureGen was announced in February 2003, as a $1 billion public-private partnership to create a 275-megawatt (MW), near-zero emissions coal-fired power plant. The state-of-the-art plant would use Integrated Gasification Combined Cycle (IGCC) technology to create both electricity and hydrogen, while capturing and sequestering 90% of CO2 emissions. A site in Mattoon, Illinois, had been selected for the plant, and operations were scheduled to begin in 2012. In January 2008, after investing $174 million on the project, the Bush administration withdrew its support after internal math errors lead the DOE to claim that the project nearly doubled in cost. In this restructured approach, multiple commercial plants will be funded and developed rather than a single, large plant. The plants, operational by 2015, will each produce at least 300 mw of electricity and sequester at least one million metric tons of CO2 each year. The focus will continue to be on IGCC power plants with CCS technology, but will no longer include hydrogen production. In this plan, the government will provide funding for only the CCS component of the plants, unlike in the initial FutureGen concept, where the federal government would incur 74% of rising costs. A 2009 report by the Government Accounting Office urged the DOE to reconsider the restructuring decision, calling attention to internal math errors, which misrepresented the costs of the FutureGen project. Energy Secretary Steven Chu has made a statement that the Department will consider reviewing support for FutureGen.

Companies Using CCS Technologies

At this time, there is no commercial-scale coal-fired CCS power plant in operation. The oldest CCS project, Slepiner, a natural gas plant just off the coast of Norway, has been in operation by the Norwegian national oil company Statoil since 1996. The first power plant to use "clean coal" CCS technology, The Schwarze Pumpe, opened in 2008 in Spremberg, Germany. The plant operated by the Swedish utility Vattenfall, is a pilot project, about one-twentieth the size of modern coal-fired plant. Salah, in Algeria, has been capturing and injecting CO2 into a gas field since 2004. The US and Canada have been cooperating on the Weyburn Project since 2000. Its Great Plains Synfuels Plant in North Dakota is an ICCG plant of commercial scale which pipes CO2 to EnCana Corp of Saskatchewan to enhance oil field productivity.

Pros & Cons of CCS

Proponents of CCS point to the fact that its components, i.e. carbon capture, carbon transport and carbon injection, have been successfully and safely performed for decades. The food and beverage industry, and gas and oil producers have used carbon capture technology to separate CO2 from other gases. The oil industry has been using pipelines to safely transport CO2, and then injecting it into oil reservoirs to enhance flagging production. The IEA and the IPCC have recommended CCS as a viable option for reducing greenhouse gases. The IEA recommends the construction of over 200 power plants equipped with CCS by 2030 to limit the rise in global temperatures. Policymakers have pointed to CCS as a bridge tech nology, filling the gap between dependence on fossil fuels and transition to alternative, renewable energy.

Opponents of CCS point to the health and economic risks of leaks, environmental concerns and economic feasibility. CO2 is benign and nontoxic at low concentrations. Leaks would only pose a serious health risk if the CO2 were concentrated, as it would be in shallow depressions. CO2 leakage could also create local effects: Ground and water displacement, groundwater contamination, soil acidification and biological interactions. CO2 leaks would also undermine climate change goals and could have economic repercussions if a company was given rebates or some form of incentive for storing CO2. Greenpeace argues that it is impossible to be certain that the CO2 will not leak. When CO2 dissolves in water it forms an acid, which could create leaks. A leakage rate of just 1% a year would result in dispersal back into the environment of over 50% of the CO2 in 100 years. One of the greatest criticisms of CCS is that the money, time and energy spent on it would better be spent on renewable energy rather than increasing dependence on coal.

Another concern is the health risk posed by coal mining in general, both to the miners themselves as well as the communities surrounding the mines. Environmentalists also point to the effect that coal mining has on its surrounding community. 750,000 to 1 million acres of hardwood forests have been eliminated in Appalachia in the last two decades as a result of the mining industry.

Currently, the greatest barrier to large-scale CCS adoption by power companies is cost. At this point, there is no large-scale commercial coal plant using CCS tech nology. The technology is expensive and unproven and the utilities industry is not known for risk-taking. The energy required to separate, compress, transport and inject CO2 will use up a quarter or more of the power station's output. CCS power plants will need to be at least a third larger than their non-CCS counterparts to generate the same amount of power. The cost of a full-scale CCS plant is estimated at anywhere from $1 billion to $1.8 billion. The estimated cost of CO2 emissions avoided through CCS is estimated at anywhere from $40-$150/ton. It is estimated that the cost of carbon emissions will rise as governments put more stringent regulations in place, and that the cost of CCS will fall as the technology matures.

Barriers to CCS

Because of current costs, CCS is not a feasible economic strategy for power companies. Supporters of

CCS technology are advocating for the following legislation and/or regulations:

- Require all newly-constructed coal power plants to meet "emissions performance" standards that limit CO2 emissions to CCS levels.
- Establish a greenhouse gas cap-and-trade system.
- Impose carbon taxes.
- Provide subsidies to plant developers to offset the cost differences between building conventional and CCS plants.
- Create a new regulatory framework for evaluating, permitting and monitoring sequestration sites and for liability for long-term CO2 storage.
- Create an accounting system to measure stored CO2.
- Address the long-term liability concerns: Who will be liable for CO2 injection and storage after the wells are full and capped – injector, property owner or government?

Regulatory Environment

- The Kyoto Protocol. The Kyoto Protocol, which was signed in 1997, requires industrialized country signatories to reduce greenhouse gas emissions from a 1990 baseline by an average of 5.2% by 2012. It also allows for international trading of emissions reductions and the establishment of the Clean Development Mechanism (CDM) which enables high volume emitters to claim credits for reductions purchased in developing countries. Although most developed nations ratified the Kyoto Protocol, the US did not. As a result, US businesses are not subject to its requirements. This status may change under the Obama administration at the next meeting in Copenhagen later this year. CDM has not yet approved CCS as a qualifying methodology from emission credits. So far, two CCS projects have been submitted to the CDM; they are on hold pending the outcome of the review process. Inclusion of CCS has been controversial, primarily due to the fact that the CDM crediting period is shorter than the geologic storage period. The legal responsibility and liability issues for long-term geologic storage have yet to be determined by any legal system.
- United States – Federal Regulations. It is anticipated that Congress will place some form of carbon restrictions on corporations in the United States in the next two to three years. The most likely outcome is a federally mandated cap-and-trade system, whereby businesses are given specific carbon reduction targets. In a cap-and-trade system, businesses must reduce their emissions by a certain percentage from a prior year (known as a baseline year). It is likely that by conducting CCS, businesses would be provided with credits to offset their carbon production. A number of federal agencies are currently developing regulations regarding the emerging technology of CCS.

The US Environmental Protection Agency (EPA) regulates the underground injection of various substances, including CO2, through its Safe Drinking Water Act (1974). Existing CO2 injections for the purposes of EOR are regulated through the EPA's Underground Injection Control (UIC) program as Class II injection wells. On July 25, 2008, the EPA proposed establishing a new Class VI category of underground injection focused on geologic sequestration. The regulations would apply only to CO2 containment, and not to its capture or transport. The requirements would set minimum technical criteria for geologic site characterization; area of review and corrective action; well construction, operation, integrity testing and monitoring; well plugging; post-injection site care; and site closure. The rules are similar to Class II, but more restrictive. If a company were to limit its CO_2 injections to EOR, only the requirements for Class II would apply. The final regulation from the EPA is expected in late 2010 or early 2011.

The Pipeline and Hazardous Materials Safety Administration (PHMSA) of the Department of Transportation (DOT) is responsible for pipeline safety regulation under the Hazardous Liquid Pipeline Act of 1979. Under the act, the DOT regulates the design, construction, operation, maintenance, and spill response planning for CO_2 pipelines. The DOT regulations classify CO_2 as a Class 2.2 (non-flammable gas) hazardous material and not as a hazardous liquid. CO_2 pipelines are not subject to federal economic regulations, but are subject to considerable oversight at the state level.

It is unclear whether the Resource Conservation and Recovery Act (RCRA) (1976) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (1980) will apply to injected CO_2. The EPA did not make a categorical determination as to whether injected CO_2 is "hazardous" under the RCRA or CERCLA. In regular concentrations, CO_2 is nontoxic. Instead, whether injected CO_2 is consid ered hazardous depends on how it is captured, whether other pollutants are combined with it and where it is stored.

The Interstate Oil and Gas Compact Commission (IOGCC) established a Geological CO_2 Sequestration Task Force, funded by the DOE and NETL, which created a Model Statute proposing legalities of ownership and liability of injection site. The Statute proposes that pore space used for CO_2 storage should follow the same property laws that apply in a given state for natural gas storage. At this point, there is no clear definition of the rules governing a site once the reservoir is full. Currently, when an EOR project is complete, the injection wells are plugged according to state regulations and all operations come to an end. Under existing rules, all monitoring for leakage and possible migration also comes to an end. This is an issue that must be addressed in upcoming legislation.

- United States – State & Regional Regulations. While the federal government is still developing regulations and legislation around CCS, many states have moved forward. States with a strong energy industry presence, i.e. Texas, Wyoming, North Dakota, New Mexico, Kansas, California and Pennsylvania, have been at the forefront of these efforts. Many of the unresolved issues surrounding CCS regulations relate to state regulations such as ownership of subsurface pore space, ownership of injected CO_2, and long-term responsibility and liability.

The Northeast Regional Greenhouse Gas Initiative (RGGI) was formed in 2005 by ten Northeast and Mid-Atlantic states including Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. The participating states have agreed to a regional cap-and-trade program initially covering CO_2 emissions from fossil fuel-burning power plants. The Western Regional Climate Action Initiative (WCI), a coalition made up of California, New Mexico, Arizona, Washington and Oregon, was formed in January 2007 to reduce greenhouse gas emissions. The Midwestern Greenhouse Gas Reduction Accord, made up of ten Midwest states has adopted the Energy Security Climate Stewardship Platform. At this point, neither the RGGI or WCI rules include CCS among the qualifying offset techniques at this time. The inclusion of CCS may be revisited at a future date. The Midwestern Accord's platform does address geologic sequestration and calls for the creation of a regional structure to transport and store CO_2.

California's AB 32, passed in 2006, seeks to reduce greenhouse gas emissions in the state by 25% by 2020 and promotes the establishment of an allowance trading system. It is not clear how CCS technology would play into the trading system. In

2007, the state released Geologic Carbon Sequestration Strategies for California, a report analyzing the regulatory and statutory issues surrounding CCS.

In 2009, Illinois signed into lay the Clean Coal Portfolio Standard Act, which creates a mandatory requirement for load-serving entities to purchase up to 5% of their electricity from facilities that reduce CO2 emissions by at least 50% and ensure that other emissions are no higher than IGCC units.

Kansas enacted a statute, which requires the state regulatory commission to establish rules and regulations for geologic storage and provides tax incentives for CCS equipment. The statue also blocks the construction of new coal plants that do not control their CO2 emissions. Legislation HB 2711 was introduced to block the statute; if the bill is passed, plants could be built with minimal commitment to emissions decreases and no requirement for CCS now or in the future.

In April 2007, New Mexico signed into law the Advanced Energy Tax Credit Bill, offering the first tax credit in the US for carbon capture technology. The bill offers upwards of $60 million in tax credits for spending on CCS projects and requires coal-fired power plants seeking credits to meet emissions limits of 1,100 pounds of CO2 emissions per megawatt-hour. In June of 2007, the New Mexico Energy, Minerals, and Natural Resources Department (ENMRD) released its report on CCS, Carbon Dioxide Sequestration: Interim Report on Identified Statutory and Regulatory Issues, which outlines the questions that must be resolved to provide the regulatory certainty necessary for a commercial CCS industry.

Oklahoma legislation was recently passed to authorize the appointment of an Oklahoma Geologic Storage of Carbon Dioxide Task Force. The legislation also includes provisions acknowledging that the capture, recovery and geologic storage of CO2 will benefit the state's citizens and that the current state statutes and agency rules governing CO2 for EOR purposes are sufficient to protect the environment and human health.

Texas is proposing House Bill 469, a tax incentive for companies developing carbon capture and EOR technologies. New coal-fired plants would be required to capture at least 60% of CO2 emissions and sequester it using EOR technologies.

In March 2008, Wyoming signed into law two bills attempting to establish a legal framework for CCS. HB 90 authorized the Department of Environmental Quality to regulate the injection and geologic storage of CO2. HB 90, the "Ownership of Subsurface Voids" bill, codifies the regulations for subsurface ownership, which resides with the surface estate owner. The bill also stipulates that the injected CO2 is owned by the injector, unless willfully abandoned.

- European Union (EU) Regulations. The EU Emissions Trading Scheme (ETS) is a cap-and-trade system at the heart of the EU's goals to cut greenhouse gas emissions 20% from their 1990 levels by 2020. In 2008, the UE passed legis lation requiring its members to create a legal framework to address the capture, transport and geologic storage of CO2. The legislation would remove existing legal barriers to CCS technology, so that it could be applied to coal-fired plants as early as 2020.
- Canadian Regulations. Beginning in 2008, the Alberta government is requiring companies emitting more than 100,000 metric tons/year of CO2 to reduce their emissions by 12%. Those companies not meeting targets may buy offsets or pay $15/ton over the limit. The Alberta government is the first in North America to impose such restrictions. Alberta's energy department will also award $2 billion (Canadian) in funding for three to five contracts for small-scale pilot CCS projects.

Stalled Public CCS Initiatives in 2010 & 2011

Governments in Canada and the UK are learning that while CCS has promise, its implementation takes longer than initially thought. The same might be said for almost all new or experimental green initiatives. At the end of February 2011, the Canadian government was far behind schedule on almost all of its environmental initiatives and CCS was no different. The province of Alberta budgeted $100M for CCS in 2011 but believes it will only be able to spend $73M. Canadian officials placed part of the blame on slow application and contract processes. Ultimately, officials do not feel confident that enough operational headway will be made during 2011 to utilize the entire sum of money that was intended for expenditure. The remaining $27M has not been withdrawn from the budget. Instead, it will be carried over to the next fiscal year.

In the EU, CCS is losing support among policy makers and investors given the poor global economic climate. CCS investors recognize the potential for high profits but believe that the initial projects should progress with the aid of government subsidies. Since these subsidies have yet to appear, very few EU members have enacted tangible initiatives. In fact, there is growing debate between lawmakers and private investors, with both sides digging in and using firmer language as to why the other party should fund CCS projects. As a consequence, the EU is expected to miss its emissions targets by the end of 2012.

The only exceptions to this trend appear in the UK and the Netherlands. The UK has pledged £1 billion to a CCS project in Scotland, while the Netherlands has contributed £42 million to a similar project. The UK is bullish about CCS' potential, with Deputy Prime Minister Nick Clegg appearing in front of 100 manufacturers in February 2011 to outline the country's CCS investment strategy. Clegg identified CCS as a vital part of reducing the UK's CO2 emissions and launched a new publication in partnership with the Special Metals Forum (SMF): Carbon Capture and Storage: Technology, Materials and Key Players. The publication is intended to highlight opportunities for manufacturers in the sector.

Related Entities

NGOs

Carbon Sequestration Initiative

CO2GeoNet

Intergovernmental Panel on Climate Change

International Energy Agency

World Resources Institute

Governmental Organizations

Clean Coal Power Initiative

The Interstate Oil and Gas Compact Commission

National Energy Technology Laboratory

Pipeline and Hazardous Materials Safety Administration

Regional Carbon Sequestration Partnerships

US Department of Energy

U.S Environmental Protection Agency

Acronyms

- CCS – Carbon Capture and Sequestration
- CO2 – Carbon Dioxide
- CCPI – Clean Coal Power Initiative
- CDM -- Clean Development Mechanism
- DOE – Department of Energy
- EOR – Enhanced Oil Recovery
- GHG – Greenhouse Gas
- GHGP – Greenhouse Gas Protocol

- IEA – International Energy Agency
- IGCC – Integrated Gasification Combined Cycle
- IPCC – United Nations Intergovernmental Panel on Climate Change
- MW – Megawatt
- NETL – National Energy Technology Laboratory
- PCPP – Pulverized Coal Power Plant
- REC – Renewable Energy Certificate
- RGGI – Regional Greenhouse Gas Initiative
- WCI – Western Climate Initiative

References

Berlind, K., & Sussman, R. (2007, May 31). Global warming and the future of coal. *Center for American Progress.* Retrieved May 15, 2009, from http://www.americanprogress.org/issues/2007/05/coal_report.html

Blankinship, S. (2009). Back to the FutureGen. *Power Engineering, 113*(4), 22-24. Retrieved May 11, 2009, from EBSCO Online Database Academic Search Complete. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=37793205&site=ehost-live

Brooymans, H. (2011, February 24). Spending Plans for carbon capture, green transit stalled. The Vancouver Sun. Retrieved February 28, 2011, from http://www.vancouversun.com/business/Spending+plans+carbon+capture+green+transit+appear+stalled/4342513/story.html

Carbon capture R&D gets $8 billion boost. (2009). *Power Engineering, 113*(4), 16-18. Retrieved April 28, 2009, from EBSCO Online Database Academic Search Complete. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=37793202&site=ehost-live

CCS 'on track but running late.' (2011, February 23). UtilityWeek. Retrieved February 28, 2011, from http://www.utilityweek.co.uk/news/news_story.asp?id=195084&title=CCS+%27on+track+but+running+late%27

de Guzman, D. (2009). Capturing carbon's potential. *ICIS Chemical Business, 275*(3), 20-22. Retrieved April 30, 2009, from EBSCO Online Database Business Source Complete. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=36527164&site=ehost-live

Dinca, C., Badea, A., Apostol, T., & Lazaroiu, G. (2009). GHG emissions evaluation from fossil fuel with CCS. *Environmental Engineering & Management Journal (EEMJ), 8*(1), 81-89. Retrieved April 30, 2009, from EBSCO Online Database Environment Complete. http://search.ebscohost.com/login.aspx?direct=true&db=eih&AN=36935107&site=ehost-live

Enzi, M. & Casey, B. (2009, July 22). Casey, Enzi introduce bill to encourage private investment in carbon capture and storage. FDCH Press Releases, Retrieved January 13, 2009, from EBSCOhost Online Database Newspaper Source Plus. http://search.ebscohost.com/login.aspx?direct=true&db=n5h&AN=32X0194337187&site=ehost-live

Gibbins, J. (2009). Carbon challenge: Engineers need to come up with a way for people to use fossil fuels without putting CO2 into the atmosphere. *Engineer* (00137758), *294*(7766), 18-18. Retrieved April 30, 2009, from EBSCO Online Database Business Source Complete. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=37132212&site=ehost-live

Hassan, M. (2009). Carbon countdown. *Utility Week, 30*(4), 9-9. Retrieved April 30, 2009, from EBSCO Online Database Business Source Complete. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=36889163&site=ehost-live

Jones, C. (2006). Back where it belongs [carbon capture and storage]. *Power Engineer, 20*(5), 14-17. Retrieved May 10, 2009, from EBSCO Online Database Business Source Complete. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=23356928&site=ehost-live

Marston, P., & Moore, P. (2008). From EOR to CCS: The evolving legal and regulatory framework for carbon capture and storage. *Energy Law Journal, 29*(2), 421-490. Retrieved May 11, 2009, from EBSCO Online Database Business Source Complete. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=35898903&site=ehost-live

Nick Clegg reinforces government's commitment to carbon capture and storage at SMF event. (2011, February 24). Retrieved February 28, 2011, from Process & Control Today. http://www.pandct.com/media/shownews.asp?ID=28168

Peckham, J. (2009). Gasification incentives survive in US economic stimulus bill. *Gasification News, 12*(4), 25-25. Retrieved May 12, 2009, from EBSCO Online Database Business Source Complete. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=36795435&site=ehost-live

Peckham, J. (2009). Workshop: CCS risks 'appear small & manageable'. *Gasification News, 12*(7), 27-27. Retrieved April 28, 2009, from EBSCO Online Database Business Source Complete. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=37805333&site=ehost-live

Policy confusion holds up carbon capture progress. (2009, March). *ENDS (Environmental Data Services*), (410), 15-16. Retrieved April 30, 2009, from EBSCO Online Database Business Source Complete. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=37602420&site=ehost-live

Pollak, M., & Wilson, E. (2009). Risk governance for geological storage of CO2 under the Clean Development Mechanism. Climate Policy (Earthscan), 9(1), 71-87. Retrieved April 30, 2009, from EBSCO Online Database Academic Search Complete. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=36379964&site=ehost-live

Raleigh, P. (2009, May). UK launches bold plan for CCS. *Process Engineering, 90*(3), 6-6. Retrieved January 15, 2010 from EBSCOhost Online Database Business Source Complete. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=41983556&site=ehost-live

Rice, J. (2009). Putting clean coal to the test. *Discover, 30*(2), 18-18. Retrieved April 30, 2009, from EBSCO Online Database Academic Search Complete. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=36404671&site=ehost-live

Scrubbing the skies. (2009). *Economist, 390*(8621), 22-24. Retrieved April 28, 2009, from EBSCO Online Database Academic Search Complete. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=36872090&site=ehost-live

Shell pulls the plug on wind and solar power. (2009). *ENDS (Environmental Data Services)*, (410), 10. Retrieved April 30, 2009, from EBSCO Online Database Business Source Complete. http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=37602411&site=ehost-live

Stephens, J., & Van Der Zwaan, B. (2005). The case for carbon capture and storage. *Issues in Science & Technology, 22*(1), 69-76. Retrieved May 10, 2009, from EBSCO Online Database Academic Search Complete. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=18514439&site=ehost-live

The illusion of clean coal. (2009, March 7). *Economist, 390*(8621), 20-22. Retrieved April 28, 2009, from EBSCO Online Database Academic Search Complete. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=36870717&site=ehost-live

Trouble in store. (2009). *Economist, 390*(8621), 74-75. Retrieved April 28, 2009, from EBSCO Online Database Academic Search Complete. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=36872206&site=ehost-live

US Department of Energy. (2008). *Carbon sequestration atlas of the United States of America and Canada.* Retrieved May 15, 2009, from http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/2008%20ATLAS_Introduction.pdf

World Resources Institute. (2009). *CCS overview: What is CCS?* Retrieved May 15, 2009, from http://www.wri.org/node/10042