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Cold Yucca Mountain: Is Carbon Capture & Sequestration the Coal Industry's Gordian Knot?

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About the Author

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After graduating from Western State College of Colorado with a double B.A. in Math and Chemistry, he served six years in the Nuclear Navy.

In 1992 Eric attained his M.S. in Nuclear Engineering at the University of Wisconsin-Madison. He then joined Molten Metal Technology in Fall River, MA, as Director of Nuclear Research, where he developed and deployed nuclear applications for hazardous waste management.

Returning to Wisconsin in 1997, Eric attained his Ph.D. in Engineering Physics. Joining the Idaho National Laboratory in 1999, he contributed to development of a Generation IV lead-bismuth cooled reactor and thoria-urania fuel. He also supported the President''s Climate Change Technology Program.

As the American Nuclear Society''s 2005 Congressional Fellow, Dr. Loewen worked in the office of Senator Chuck Hagel (R-NE) where he coordinated the Senator''s inclusion of America''s first legislation addressing global climate change policy into the Energy Act of 2005.

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Introduction

The subject of climate change is complex and many of the forces which drive it are poorly understood. Increasing levels of carbon dioxide (CO_2), giving rise to increases in temperature, are commonly blamed for recent changes in glaciation and sea ice, among other phenomena. One proposal seeks to address this complex issue with one simple solution: since humans are releasing naturally sequestered CO_2 by burning fossil fuels, they can replicate what nature has done over millennia by re-sequestering the emitted CO_2. It is often suggested as well that there will be very little economic or environmental penalty to forcing the CO_2 into the earth in a presumably benign manner.

This paper reviews carbon capture and sequestration (CCS) approaches and related U.S. federal research and development (R&D). I explore the energy costs to capture the very stable molecule called CO_2, which drive the economics of CCS, by keying on the Gordian Knot—selecting and developing a CO_2 repository. Yes, a repository, meaning an area under the earth that will permanently encase the CO_2, either as a gas or some sort of compound.

The tribulations suffered by the nuclear industry in their quest to open a repository stand as a warning to those who put their hope in carbon sequestration. Yucca Mountain in Nevada[1] was selected to be the site for sequestration of nuclear reactor spent nuclear fuel, including uranium and its more radioactive byproducts. Radioactive waste atoms produce heat as they decay into stable compounds. This planned nuclear industry repository would have increased the ridge temperature by 1°C in the first 100 years. Geological sequestration of CO_2 will not produce heat (except possibly at minute levels if chemical transformation occurs due to CO_2 reaction with minerals or compounds). This paper is titled "Cold Yucca Mountain" to compare and contrast CCS with our failure to site a "Warm Yucca Mountain" for geologic sequestration of nuclear waste.

Only six weeks after entering office, the Obama Administration canceled the Yucca Mountain project. This act of governmental fiat reversed decades of domestic policy development and relegated tens of billions in federal expenditures to the negative side of the budget ledger. This action also "disappeared" the billions of dollars that citizens paid as add-ons to their electricity bills for their utility companies' payments into the Nuclear Waste Fund and for the on-site storage of used nuclear fuel that should have been placed in the Yucca Mountain repository beginning in 1998. And citizens will be paying more taxes for court awards to the utilities for the government's breach of contract in the Nuclear Waste Policy Act of 1982 (NWPA).

The closure of Yucca Mountain was based on the premise that "society" did not have confidence that we can design a nuclear waste repository that can last the centuries required for the radioactive elements to decay below the natural background radiation level of uranium ore. Sequestered CO_2, on the other hand, never decays and thus could never be released from a repository, since it would again increase the levels of climate-warming greenhouse gases in the atmosphere.

Proponents of carbon sequestration therefore are faced with three challenges: how does an engineer design a CO_2 repository that will last forever? How would a regulatory agency license this repository? And how could a government guarantee to the local stakeholders that this CO_2 repository will last forever?

Like Yucca Mountain, a CO_2 repository can anticipate a multitude of stays, delays and emotionally-charged arguments from the worried populace. The industries which produce CO_2—and virtually all industries do—and society need to heed the lessons learned from the Yucca Mountain Project: decisions in the face of long-term uncertainty are difficult to make. History has proven that in our world "indecision is the decision."

The Story of Yucca Mountain

Management of nuclear waste has posed an issue for the nuclear power industry since its genesis in the 1950s, in part because of the time scales of the decisions that must be made. A used nuclear fuel bundle requires about one million years to degrade to the natural radioactive level of uranium ore.

Every major nuclear country, including the United States, has selected a geologic repository for sequestration of unused nuclear fuel. Federal policy, codified in the Nuclear Waste Policy Act of 1982 (NWPA), with amendment in 1987, is based on the premise that nuclear waste can be disposed of safely in underground disposal facilities called repositories, that is, through geologic sequestering.

The 1982 NWPA calls for disposal of used nuclear fuel in a geologic repository that is unlikely to be disturbed for 10,000 years. The Act also established an office in the Department of Energy to develop a U.S. used nuclear fuel geologic repository. A review of the site selection process, with its many lengthy and rigorous feasibility and safety studies, is appropriate:

- In 1983, the U.S. Department of Energy selected nine well-researched locations in six states for consideration as potential repository sites. The nine sites were studied and results of these preliminary studies were reported in 1985.
- Based on the reports, the president approved three sites for intensive scientific study called site characterization. The three sites were Hanford, Washington; Deaf Smith County, Texas; and Yucca Mountain, Nevada.
- In 1987, Congress amended the Nuclear Waste Policy Act and directed U.S. Department of Energy to study only Yucca Mountain.
- On July 9, 2002, the U.S. Senate cast the final legislative vote approving the development of a repository at Yucca Mountain.[2]

The Act established a fee on nuclear-generated electricity, paid into the Nuclear Waste Fund (NWF). The NWF funds were subject to Congressional appropriation and to yearly interference from Congressional opponents of the project. Thus, a legislative framework to deal with a project with an operational time of at least fifty years and a requirement to remain intact for a million years was subject to the fluctuations and vagaries of yearly budget debates.

Accentuating these annual budget debates were politically potent claims of safety, health, and environmental concerns raised by the local stakeholders and their politicians.

Nevertheless, the project proceeded, albeit slowly. After collecting a large fund that could easily cover the cost of the project, the Nuclear Waste Policy Act was amended in 1987 to select a single site, Yucca Mountain in Nevada. Yucca Mountain, or more properly Yucca Ridge, is located on the Nevada Test Site where 928 nuclear weapons were detonated between 1951 and 1992. The existing level of radiation precludes any commercial or recreational use of the area.

After numerous scientific studies and the expenditure of more than $9 billon, DOE submitted an application to the Nuclear Regulatory Commission (NRC) in June 2008 for the planned repository. Issues raised by the state of Nevada and others about the site include the likelihood of earthquakes, volcanoes, groundwater intrusion, and human intrusion. Any geological repository for CO_2 would face similar questions that are very difficult to answer when timescales exceed 10,000 years.

The questions that plagued the Yucca Mountain Project from the beginning remain frustratingly difficult to answer today. The initial goal for loading the waste into the repository starting in 1998 was missed. The second goal of 2010 will be missed because of the Obama Administration's declaration that Yucca Mountain is "not an option."

Radioactive waste is perceived as the Gordian Knot for the nuclear power industry because of the lack of a disposal system for the spent nuclear fuel. Long-term storage of waste CO_2 is the Gordian Knot for the coal power industry because CO_2 is now regarded and regulated as a pollutant, and a possible means of abatement is disposal into a geologic repository. As carbon capture and sequestration becomes a prerequisite for any future growth of coal industry, the feasibility of CO_2 geologic disposal will depend on the ability of the selected geologic formations to store CO_2 forever. Because some geologic formations are believed to have remained undisturbed for millions of years, it appears technically feasible that CO_2 as a gas or a carbonate could be isolated from the environment. There is no scientific or technical reason to preclude a satisfactory Cold Yucca Mountain geological repository from being established, but local stakeholder acceptance may be as problematic as Yucca Mountain was for nuclear power.

The Yucca Mountain controversy drives home a serious lesson: confidence in the permanent geologic disposal of CO_2 will be difficult to achieve for specific sites. There is inherent uncertainty involved in predicting storage site performance forever. Earthquakes, for example, occur throughout the United States and could release sequestered CO_2 into the atmosphere. For that reason, opponents of the sequestration of gaseous CO_2 in geological domes have recommended using alternative technologies to reduce CO_2 into a carbonate or carbonic acid, but this approach will require more energy and more money to establish permanent sequestration.

Carbon Capture and Storage: An Overview

CCS is a process by which CO_2 is separated from the emissions stream, compressed, and transported to a below-surface (ground or seabed) location to be stored or sequestered permanently. The U.S. Department of Energy's (DOE) Office of Fossil Energy leads this portfolio of research at cost of ~$300 million in the last two years.[3]

The capture of CO_2 is particularly important for the future of coal, the most abundant fossil fuel in the U.S., which currently fuels about half of the country's power plants.

Basically the three reactions for CO_2 capture are:

- Absorption, either chemical and physical, in a geologic formation;
- Adsorption, either physical and chemical, in a geologic formation. (Adsorption differs from absorption in that adsorbed material adheres to the surface of a solid, whereas absorbed material permeates a solid or liquid.);
- Mineralization and biomineralization within the geologic repository. (In biomineralization, microorganisms precipitate carbon dioxide from water and sequester it as a solid carbonate mineral, much as oysters build their shells from calcium carbonate dissolved in seawater.)

Many geologic structures have contained crude oil, natural gas, brine, radioactive compounds and CO_2 over millions of years. But we are now just beginning to understand the behavior of CO_2—and how it moves within the geologic formation and what the physical and chemical changes within the formation are. We really do not know what will or might happen when we re-inject large amounts of CO_2 rapidly into geologic formations.

A variant form of sequestration technology is enhanced oil recovery. In this process, CO_2 is injected into oil and gas fields, increasing field pressure and decreasing the viscosity of the oil within the porous geologic formation to "push" out the oil and gas and so increase the quantity recovered. The U.S. is the world leader in enhanced oil recovery technology, injecting 32 million tons of CO_2 per year for this purpose, of which more than 90% comes from natural accumulations of CO_2 found in geologic domes. From the perspective of a sequestration program, enhanced oil recovery represents an apparent opportunity to sequester carbon at low cost, due to the revenues from recovered oil and gas. But will that reduce overall CO_2 emissions? When CO_2 is injected into an oil field, additional fossil fuel is recovered, which is burned and releases CO_2. So this is not the answer to reducing carbon dioxide in the atmosphere.

Nature may provide other repositories, in the form of three well-studied types of geologic formations: oil fields, coal beds and saline aquifers.

…uncertainty surrounds ownership of pore space and deep saline aquifers and the potential that CCGS might trigger liability and requirements under existing environmental protection statutes, such as the Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and the Clean Air Act (CAA).

Wendy B. Jacobs, Leah Cohen, Lara Kostakidis-Lianos and Sara Rundell, Belfer Center for Science and International Affairs, March 2009

Regulations for CO_2 storage are needed to specify: site selection criteria; well, injection, and closure operational requirements; long-term monitoring and verification requirements; and long-term liability.

Pew Center on Global Climate Change, May 2009

One of the geological challenges faced by Duke Energy and others investigating in CCS is ensuring that the pressure inside reservoirs deep beneath the surface of the earth doesn't climb too high as carbon dioxide is injected. "There are only certain safe levels that you can raise the pressure to before you get into issues of seismicity," Herzog says.

MIT Technology Review, October 5, 2009

Oil fields use CO_2 for enhanced oil recovery. Capture of the CO_2 is well understood and oil fields should be stable repositories, as long as the pressure of the reservoir is not exceeded by overpumping CO_2 into the oil or gas reservoir.

Coal beds typically contain methane gas adsorbed on the coal surface. If carbon dioxide gas is injected into a coal bed, it is adsorbed onto the surface at about twice the rate of methane. But CO_2 adsorption results in methane release. Since methane is about twenty times more potent a greenhouse gas than CO_2, the net gain from a climate standpoint is hard to justify. Sequestration in coal beds might be economical if the released methane is recovered and burned to create a revenue stream. The U.S. has 6 trillion tons of coal beds, of which 90 percent is unmineable due to seam thickness, depth, and structural integrity. These beds represent potential capture sites for CO_2.

Saline aquifer formations can sequester CO_2 in the form of carbonic acid or as dissolved carbonates in the saline water. The estimated carbon storage capacity of saline formations in the U.S. is large and the Office of Fossil Energy estimates that deep saline formations in the U.S. could potentially store 500 billion tones of CO_2. The U.S. emits about 3.5 billon tones of CO_2 a year in the electric and industrial sectors, so potentially the U.S. could store 140 years worth of sequestration storage in saline formations. The Norwegian oil company Statoi, has injected one million tons a year of recovered CO_2 back into a saline aquifer formation under their oil platform in the Norwegian Sea, equivalent to the yearly output of a small 150-megawatt coal-fired power plant. The typical fossil fueled power plant generates 1,000-megawatts. Finding suitable sites for the U.S.'s 3.5 billion ton-annual output would be a significant challenge.

Marine (or Ocean) Sequestration has not yet been studied to the extent that terrestrial sequestration has been studied, but the ocean also is being considered as a CO_2 repository. SCS Energy has proposed capturing and liquefying CO_2 from a coal-fired plant and pumping it 70 miles out to sea where it will be injected into porous sandstone below the seabed. The 500-megawatt plant and the CO_2 sequestration process is tentatively priced at $5 billion.[4, 5] If CO_2 leaks from a repository, it will react with seawater to produce carbonic acid. A small leak would be significantly diluted by the volume of the ocean waters, but this form of sequestration will be unpopular with some environmental groups.

Energy Costs of CCS

The previous sections have discussed the basic reactions for capture: absorption, adsorption or mineralization, but these assume a relatively pure stream of CO_2. In the case of Statoi, oil requires the step of CO_2 separation from natural gas. In this case, the cost improves the natural gas going to market. Coal plants, on the other hand, combust coal in the air (~20% O_2 and 80% N), creating a CO_2 gas stream mixed with nitrogen in its exhaust. The nitrogen present interferes with the three basic reactions, that is why there are efforts to combust coal in pure oxygen so that the resulting stream has a higher concentration of CO_2.

> …a likely representative range of costs of abatement for capture (and excluding transport and storage) appears to be $100-150/t CO_2 for first-of-a-kind plants and plausibly $30-50/t CO_2 for nth-of-a-kind plants.
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> *Mohammed al-Juaied and Adam Whitmore, Belfer Center for Science and International Affairs,* July 2009
>
> Any conceivable carbon capture technology for coal-fired power plants will increase the cost of electricity generation from affected plants because of efficiency losses.
>
> *"Capturing CO_2 from Coal-Fired Power Plants: Challenges for a Comprehensive Strategy," Congressional Research Service RL34621,* August 15, 2008

In the end, the capital cost and the R&D cost to develop the separation and combustion technologies is difficult to estimate. The energy, however, to inject the CO_2 into the "Cold Yucca Repository" will take at least 30% of the electrical power generated. This is a significant use of the output from any coal generation plant, impacting the overall economics.

The Economics of CCS and Nuclear Waste Storage

Table 1 compares the issues of storing CO_2 (the Cold Yucca Mountain) and those of storing used nuclear fuel (the Warm Yucca Mountain). Despite the differences between radioactive waste and the common by-product of respiration, the lessons of disposing of one should be heeded in trying to dispose of the other.

The scientific community has considered and evaluated CCS for a relatively short period of time relative to the time spent on studying used nuclear fuel. Since 1957, fifty-five National Academy of Science studies have deemed deep geologic disposal to be the safest approach to the sequestration of used nuclear fuel. Many additional studies by our national laboratories and by international scientific bodies have also explored the options and alternatives to nuclear waste disposal. And since the NWPA was signed into law in 1982, more than thirty-six years of science have clarified the technical issues in siting and development of a repository for our nation's used nuclear fuel.

The NWPA created a fund, paid into by consumers of electricity, but held by the government. The Department of Energy was to use that fund to study, test, design and submit a license application subject to approval from two other government agencies, the Nuclear Regulatory Commission and the Environmental Protection Agency. Contributions to the fund plus interest currently exceed $30 billion. Nine billion dollars of the fund were spent on site characterization, which started with three sites and ultimately focused only on Yucca Mountain. The courts have affirmed the federal government's obligation to dispose of used fuel in accordance with this 1982 law and taxpayers face up to $11 billion in liability costs now that the legislative approach from 1982 has been suddenly abandoned.

> …before widespread global application large scale storage projects to be undertaken during the next decade need to demonstrate the feasibility of CCS and to answer major remaining questions: (i) What actually happens to CO_2 in the subsurface and how do we know what is happening? (ii) Can we monitor CO_2 once it is injected? (iii) What techniques are available for monitoring whether CO_2 is leaking? (iv) Is it possible to predict the long term storage of CO_2 in geological reservoirs?
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> *U.S. National Academy of Science,* June 2008

At present, the nuclear industry has nearly 60,000 metric tons of civilian used fuel awaiting disposal, in addition to 20,500 metric tons of defense waste stored across Department of Energy facilities. Table 1, which compares this with the amount of CO_2 that is produced each year in the United States, shows the magnitude of the effort required for CCS.

The NWPA established the Nuclear Waste Technical Review Board (NWTRB) to evaluate the scientific data and technical aspects of the now proposed Yucca Mountain Project. They have evaluated over $7.7 billion of scientific research on the Yucca Mountain as a potential repository site. This scientific work contributed to DOE's 8,600-page license application successfully docketed with the Nuclear Regulatory Commission. The Commission, the independent agency with the expertise and responsibility to assess the safety of a potential repository at Yucca Mountain, will spend more than four years evaluating the application. The Commission only commenced its review September 2009. Neither the NAS nor the NWTRB has presented any evidence to disqualify Yucca Mountain as a repository. And yet all this scientific and regulatory effort has been thrown out due to local political pressure and fear mongering.

Some level of resistance should be expected in siting CCS facilities around the country, because of the real and perceived risks of instant death if there was a large release of CO_2. Given the immediate consequence of deaths with a release, it seems unlikely that any CCS system, other than for oil recovery, will be completed in my lifetime.

Here are the sorts of questions any CCS site must face:

1. What is the legislative process to establish the government responsibilities for siting, building, operating, licensing, monitoring, and future CCS sites?
2. What is the legal basis for the determination to site a CCS?
3. What research or scientific work produced by the National Academy of Sciences or other organization proves that CCS can be accomplished on the scale required for our current fleet of coal fired plants.
4. Will the CCS decision cause delays in the construction of future coal plants?
5. What significant scientific findings are anticipated to prove that CCS is an economically viable process?

Although the general public is still largely unfamiliar with CCS, there are early indications that community acceptance may prove a significant challenge to the siting of CCS infrastructure in the United States.

"Community Acceptance of Carbon Capture and Sequestration Infrastructure: Siting Challenges," Congressional Research Service RL33801, July 29, 2008

Stumpe, a 28-year old veterinarian, is "not a violent man," he says. "But there are people here who will do whatever it takes to stop this."

Wall Street Journal, October 6, 2009 an article titled "Locals Try Sinking Plan to Store CO_2 Underground."

"… people are worried about leaks… they worry their kids will be suffocated, their cows will die, their property values will slump."

Thomas Lautsch, Vattenfall Europe AG's head of CO_2 storage.

Table 1. Nuclear Waste Repository as compared to CCS

Issue	Nuclear Waste	CCS
Scientific study before major policy legislation is enacted	33 years	4 years
When legislation enacted	1982	2005
Length to first repository	Initial plan was ~20 years, at this point there is no schedule	Plan on the same time frame
Estimated mass of waste to be sequestered	70,000 MT for over 40 years of nuclear power generation	70,000 MT of CO_2 is equivalent to 20 days of coal emissions in the U.S.
Number of repositories needed	1 to 2 (future advances in fuel cycles will decrease this amount)	Greater than 100
Estimated cost of a repository	$92 billion full life cycle costs	$90 billion x 100 is well north of $1 trillion
Repository lifetime	1,000,000 years for direct disposal; 300 years when using sodium cooled reactor technology	Forever
NAS studies	55	12
National Laboratories studies	Numerous	Numerous
Scientific oversight	Nuclear Waste Technical Review Board	None
Regulatory Body	NRC and EPA	EPA, USFS, DOA?
Government Agency legislative responsible to develop repository license	DOE per the Atomic Energy Act	Nothing currently exists

As Table 1 illustrates, CCS has many policy, regulatory, scientific and economic hurdles to overcome before it can be used on a scale that could significantly reduce CO_2 emissions.

Another inconvenient fact relates a Cold Yucca Mountain with the Warm Yucca Mountain—deaths. Since a nuclear repository has never been opened, it has never taken a human life. CCS cannot make the same claim. In 1986, carbon dioxide naturally sequestered in the bottom of Lake Nyos in Cameroon suddenly and spontaneously discharged and the resulting cloud suffocated more than 1,700 people as well as their animals. Lake Nyos will be the Love Canal of CCS. This episode will make it difficult for local stakeholders to embrace a carbon sequestration site in their neighborhood.

Policy Choices

America has the economic wherewithal to determine its coal energy future by the policy choices it makes. The electrification trend will continue and demand for coal will increase. The Energy Information Administration projects rising demand for coal in the U.S. through 2030 as do the International Energy Agency's global projections. Future examination of CCS policies and R&D investments should appreciate four fundamental realities:

1. The American economy relies heavily on electricity. Fifty percent of our electricity now comes from our coal-powered power plants. Future economic growth will require yet more electricity from coal power and other sources. The more cheaply we can obtain the additional energy, the better off we will be.
2. *Repository* storage of CO_2 or compounds of CO_2 cannot be accomplished any time soon, and future generations would be better served by addressing other environmental and societal issues.
3. CCS is a policy choice being considered by other countries with less landmass than the United States, who realize that it requires a permanent government subsidy to keep this process going. The U.S. would be well served to monitor these activities.
4. CCS appears to have no chance of being economically successful, but policy choices are not free. The United States will need an integrated demonstration to convince the public and commercial investors, before CCS could be considered.

The coal industry should not agree to pay any long-term fee for a future CO_2 repository. Such a requirement represents government intervention into the market place and a commitment that the government may not be able to meet. But if the coal industry agrees to some fee, it should not be subject to the yearly budget appropriations, because large long-term capital projects typically fail with this type of yearly control.

Currently there exists no policy framework by the U.S. government to resolve the technical issues of establishing a CCS site. Such a framework must be established with a program, milestones, and funding before any climate legislation can take any credit for future CCS offsets. Consequently, to the extent this framework is established, one can gauge the risk after informed public comment. The coal industry, utility operators, and the electric utility customers will confront constant changes in laws and regulations and the state of scientific knowledge if a policy framework for CCS is established.

The National Environmental Policy Act (NEPA) will require an environmental analysis on the impact on CO_2 storage on future generations. Under NEPA, a prospective CCS site will have to guarantee that safe and adequate storage is technologically and economically feasible. The reckless decisions made in the current climate legislation, glibly assuring that technological advancement can be counted upon to make CCS workable in the future, will be insufficient to meet NEPA's demands.

Plainly put, based on America's experience with attempting to store used nuclear fuel at Yucca Mountain, the parallel of a Cold Yucca Mountain filled with tons of CO_2 is particularly problematic.

Substantial resources have been and will continue to be devoted, needlessly or inefficiently, to this project, in the areas of Congressional action (authorization legislation and appropriations), legal, technical, and local stakeholder involvement, construction, and much more. Given the enormous demands that will be placed on all participants, the process presupposes an unachievable timetable for compliance and an illusory timetable for storage of CO_2. Can a fair and impartial hearing for any CCS repository can be completed in the prehearing and hearing process? What government agency will have the powers necessary to achieve those ends? Opponents of coal-based energy have set the industry on a fool's errand, since their ultimate goal is not to sequester coal's CO_2 emissions but to stop the use of coal. In spite of the industry's efforts to find technical solutions to CO_2 storage, such solutions may be irrelevant, as demonstrated at Yucca Mountain, where politics in the end overturned decades of scientific research and billions in expenditures.

Appendix A: Summary of Legislative Action

H.R. 3981 (Barton)
Reclassifies fees paid into the Nuclear Waste Fund as offsetting collections.
Introduced March 17, 2004; referred to Committee on Energy and Commerce.
Approved by committee June 24, 2004, by vote of 29-19 (H.Rept. 108-594).

CRS RL33801
Carbon Capture and Sequestration (CCS)
June 19, 2009

Summary

Carbon capture and sequestration (or storage) known as CCS has attracted interest as a measure for mitigating global climate change because large amounts of carbon dioxide (CO_2) emitted from fossil fuel use in the United States are potentially available to be captured and stored underground or prevented from reaching the atmosphere. Large, industrial sources of CO_2, such as electricity-generating plants, are likely initial candidates for CCS because they are predominantly stationary, single-point sources. Electricity generation contributes over 40% of U.S. CO_2 emissions from fossil fuels. Congressional interest has grown in CCS as part of legislative strategies to address climate change. On February 13, 2009, Congress passed the American Recovery and Reinvestment Act of 2009 (ARRA, P.L. 111-5), which included $3.4 billion for projects and programs related to CCS. Of that amount, $1.52 billion would be made available for a competitive solicitation for industrial carbon capture and energy efficiency improvement projects, $1 billion for the renewal of FutureGen, and $800 million for U.S. Department of Energy Clean Coal Power Initiative Round III solicitations, which specifically target coal-based systems that capture and sequester, or reuse, CO_2 emissions. The $3.4 billion contained in ARRA greatly exceeds the federal governments cumulative outlays for CCS research and development since 1997. The large and rapid influx of funding for industrial-scale CCS projects may accelerate development and deployment of CO_2 capture technologies. Currently, U.S. power plants do not capture large volumes of CO_2 for CCS, even though technology is available that can potentially remove 80%-95% of CO_2 from a point source. This is due, in part, to the absence of either an economic incentive (i.e., a price for captured CO_2) or a regulatory requirement to curtail CO_2 emissions. In addition, DOE estimates that CCS costs between $100 and $300 per metric ton (2,200 pounds) of carbon emissions avoided using current technologies. Those additional costs mean that power plants with CCS would require more fuel, and costs per kilowatt-hour would be higher than for plants without CCS. After CO_2 is captured from the source and compressed into a liquid, pipelines or ships would likely convey the captured CO_2 to storage sites to be injected underground. Three main types of geological formations are being considered for storing large amounts of CO_2 as a liquid: oil and gas reservoirs, deep saline reservoirs, and unmineable coal seams. The deep ocean also has a huge potential to store carbon; however, direct injection of CO_2 into the deep ocean is still experimental, and environmental concerns have forestalled planned experiments in the open ocean. Mineral carbonation reacting minerals with a stream of concentrated CO_2 to form a solid carbonate is well

understood, but it also is still an experimental process for storing large quantities of CO_2. The increase in funding for CCS provided for in ARRA and by other economic incentives may lead to less expensive and more effective technologies for capturing large quantities of CO_2. Without a carbon price or a regulatory requirement to cap CO_2 emissions, however, it will be difficult to predict or evaluate how the technology would be deployed throughout the U.S. energy sector. By comparison, transporting, injecting, and storing CO_2 underground may be less daunting. A large pipeline infrastructure for transporting CO_2 could be very costly, however, and considerable uncertainty remains over how large quantities of injected CO_2 would be permanently stored underground. To help resolve these uncertainties, DOE has initiated large-scale CO_2 injection tests in a variety of geologic reservoirs that are to take place over the next several years.

CRS RL34005
Energy Savings Act of 2007 (S. 1321): Summary of Major Provisions
May 17, 2007

Summary

The Energy Savings Act (S. 1321) puts forth a broad range of proposals on biofuels, energy efficiency, and carbon storage. The Senate Committee on Energy and Natural Resources approved the bill by a vote of 20 to 3, on May 7, 2007. Title I, the Biofuels for Energy Security and Transportation Act, is taken primarily from S. 987, with a few other provisions added in markup by the Committee. That title would increase the renewable fuel standard, set some standards for greenhouse gas emissions reductions, and provide support for fuel infrastructure, feedstocks, and biorefineries. Title II, the Energy Efficiency Promotion Act, is drawn primarily from S. 1115. That title would set some new standards for energy efficient equipment, establish goals for fuel savings, strengthen federal energy efficiency requirements, and authorize several new programs for vehicles and grants. Title III, the Carbon Capture and Storage Research, Development, and Demonstration Act, is taken primarily from S. 962 and S. 731. That title would call for large-scale testing of carbon dioxide (CO2) storage in geological formations, establish competitive funding awards, direct that a national storage capacity assessment be conducted, and require that the Department of Energy (DOE) demonstrate the use of large-scale capture technologies at industrial facilities. This report will be updated as legislation develops.

Related Legislation:

- S.1321
- S.987
- S.1115
- S.962
- S.731

CRS RL34621
Capturing CO_2 from Coal-Fired Power Plants: Challenges for a Comprehensive Strategy
August 15, 2008

Summary

Any comprehensive approach to substantially reduce greenhouse gases must address the world's dependency on coal for a quarter of its energy demand, including almost half of its electricity demand. To maintain coal in the world's energy mix in a carbon-constrained future would require development of a technology to capture and store its carbon dioxide emissions. This situation suggests to some that any greenhouse gas reduction program be delayed until such carbon capture technology has been demonstrated. However, technological innovation and the demands of a carbon control regime are interlinked; a technology policy is no substitute for environmental policy and must be developed in concert with it. Much of the debate about developing and commercializing carbon capture technology has focused on the role of research, development, and deployment (technology-push mechanisms). However, for technology to be fully commercialized, it must also meet a market demand — a demand created either through a price mechanism or a regulatory requirement (demand-pull mechanisms). Any conceivable carbon capture technology for coal-fired powerplants will increase the cost of electricity generation from affected plants because of efficiency losses. Therefore, few companies are likely to install such technology until they are required to, either by regulation or by a carbon price. Regulated industries may find their regulators reluctant to accept the risks and cost of installing technology that is not required. The Department of Energy (DOE) has invested millions of dollars since 1997 in carbon capture technology research and development (R&D), and the question remains whether it has been too much, too little, or about the right amount. In addition to appropriating funds each year for the DOE program, Congress supported R&D investment through provisions for loan guarantees and tax credits. Congress also authorized a significant expansion of carbon capture and sequestration (CCS) spending at DOE in the Energy Independence and Security Act of 2007. Legislation has also been introduced in the 110th Congress that would authorize spending for carbon capture technology development. Other legislation introduced invokes the symbolism of the Manhattan Project of the 1940s and the Apollo program of the 1960s to frame proposals for large-scale energy policy initiatives that include developing CCS technology. However, commercialization of technology and integration of technology into the private market were not goals of either the Manhattan Project or Apollo program. Finally, it should be noted that the status quo for coal with respect to climate change legislation isn't necessarily the same as "business as usual." The financial markets and regulatory authorities appear to be hedging their bets on the outcomes of any federal legislation with respect to greenhouse gas reductions, and becoming increasingly unwilling to accept the risk of a coal-fired power plant with or without carbon capture capacity. The lack of a regulatory scheme presents numerous risks to any research and development effort designed to develop carbon capture technology. Ultimately, it also presents a risk to the future of coal.

Appendix B: National Academy of Sciences – Reports

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11. Manuel Lerdau, “The Ecology of Carbon Sequestration in Terrestrial Ecosystems,” 14th Annual German-American Kavli Frontiers of Science Symposium, June 11-14, 2008 http://www.nasonline.org/site/DocServer/Lerdau_Manuel.pdf?docID; http://www.nasonline.org/site/PageServer?pagename=FRONTIERS_gafos_2008program

Endnotes

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4. Amy Coombs, “An Ocean Trap for Carbon Dioxide,” *Technology Review*, May 14, 2009 http://www.technologyreview.com/energy/22650/?a=f.
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June 2010