carbon capture journal

Jan / Feb 2010 Issue 13

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Front cover:

Alstom's chilled ammonia pilot at AEP's Mountaineer Plant in West Virginia

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Alstom - US projects and policy

We interviewed Robert G Hilton, Alstom's Vice President Power Technologies for Government Affairs, who talked about US climate change policy and Alstom's portfolio of pilot projects.

Mr. Hilton began by summarising the current state of US climate change legislation which is passing through the Senate.

"To start with we have the Waxman-Markey bill which cleared the house and now we have regionally the Kerry-Boxer bill and a whole series of proposals that are stacking up in the Senate," he said. "The one that seems to be pulling the most interest is the framework proposed by Kerry, Graham and Lieberman which was put out just before Copenhagen, but we won't know for sure until after some serious discussions probably in January or February 2010."

"Nothing will happen in the Senate until the Healthcare bill is finished, and it's also got to take up a Financial Securities bill that the House has already passed and that actually has some fairly significant bearing on the climate bill. Assuming we end up with a cap and trade that will likely create a fairly substantial trading and derivitave market larger than anything we've looked at before and the Senate will take up that bill before it gets to climate."

"Once the Senate gets a bill together it then goes to conference committee where they will try to reconcile the Waxman-Markey bill with whatever the Senate produces. Once they do that there's two other steps – it has to go back to the House and has to be voted again – assuming it clears the Senate and remains intact, and of course a lot of people are nervous about the possibility of the House because it only passed by a slim margin to begin with. Then it goes to the President – that's the only step in the process I'm confident in, if we get a Bill to Obama he'll sign it."

"In a parallel action to this, the EPA is moving in the Supreme Court to regulate CO2 as a hazardous air pollutant. It is in the process of generating a series of rules and regulations which will lead up to its regulating CO2. If Congress passes the Bill they will take authority away from the EPA and provide direction. Congress can also take the authority in a separate action away from EPA by passing a Bill to change the authority of the Clean Air Act so EPA would not have to regulate."

"Senator Murkowski has introduced a resolution to overturn EPA's endangerment findings in a disapproval resolution. Whether this will have enough support in the Senate I don't know, it may not even have enough support in Committee, it's difficult ground. That would in effect throw this whole thing into a mess, because they'd be saying to EPA, you can't regulate this without the endangerment finding, and on the other hand we have the Supreme Court saying they have to. So you'd have to change the Clean Air Act, which they didn't really want to do."

"So the path we're walking is that if the Senate and the House don't do something, EPA will, and if EPA gets stopped by this process then it all goes into limbo, and if you're a utility it's maybe the best of all worlds. But this would collapse whatever agreement we're working on, and give no credibility to any commitments we make on climate change."

"The EPA route would have to go through a series of stages which could take around four or five years; even they are saying they would prefer it to happen through Congressional action. But if Congress fails to act, EPA have the statutory requirement to act."

"I believe somehow or other we're going to get a Bill out of the Senate, it's just a matter of when. The other thing that complicates it is that 2010 is an election year, a third of the Senate and all of the House is up for re-election. Generally speaking major legislation in a election year has to get done by mid year."

"One of the main issues is cap and trade. There are a lot of people who are favouring a collar with a trading system, there are several versions floating around but it's not clear if any of these version have enough support to make it through. We all thought cap and trade for sure, Alstom certainly supports it, we think a market based system is the best system."

The amount of international offsetting, the practice of using cheaper projects overseas to generate a carbon credit for the home market, is also contentious. "The House Bill was allowing unlimited offsets, whereas Kerry-Boxer was limiting the amount of international offsets, and these have to be reconciled. Carbon capture has not yet been included in international offset generation in the US," explained Mr. Hilton. The UN's clean development mechanism also recently failed to include CCS.

The US is also working on international cooperation with several countries including the EU and China; Alstom has a large business interest in China and sees great potential there.

Pilot projects in the US

Alstom has two current and one completed pilot in the US. The company is trialling the two processes it has under development, chilled ammonia at Pleasant Prairie and Mountaineer, and amines at Dow Chemicals.


Robert G Hilton, Vice President Power Technologies for Government Affairs, Alstom

"We are still determining the relative advantages of the two," said Mr. Hilton. "Chilled ammonia will be less energy intensive and more flexible for cycling plants because of the lack of steam requirement. In warm climates amines would have an advantage because of there is no need for cooling. We suspect there will be different levels of performance for different concentrations of CO2."

"Pleasant Prairie is now shut down," said Mr. Hilton. "We had a party there in October to celebrate the success of the project. It was designed specifically as a proof of concept plant for the chilled ammonia process, what we wanted to do was establish a number of things: that the process could be run and run continuously for as long as we wanted; that when we put the three individual processes, chilling, absorbing and regeneration together that they would harmonise; we wanted to test the quality of the CO2 stream and that we could run it at high efficiency consistently capturing 90% of the CO2 or better."

"It was the first place where we had run the process on actual flue gas.We accomplished everything that we had set out to do. In our opinion it was a resounding success."

"At Mountaineer we have a bigger plant that was more designed for purpose. Pleasant Prarie was built very quickly, and as it was a proof of concept plant it was slightly over engineered, as we didn't want to have anything that inhibited the process. We did not ever intend to specifically prove energy consumption, but we will do that at Mountaineer."

"Mountaineer had the benefit of some learnings from Pleasant Prairie plus some more time in the design phase. We started it up on 1st September and started capturing CO2 the same day, which is always a pleasant surprise as you can expect something to go wrong during initial start up. Then at the beginning of October we started sequestering CO2."

"At our third project, the Dow Chemi-

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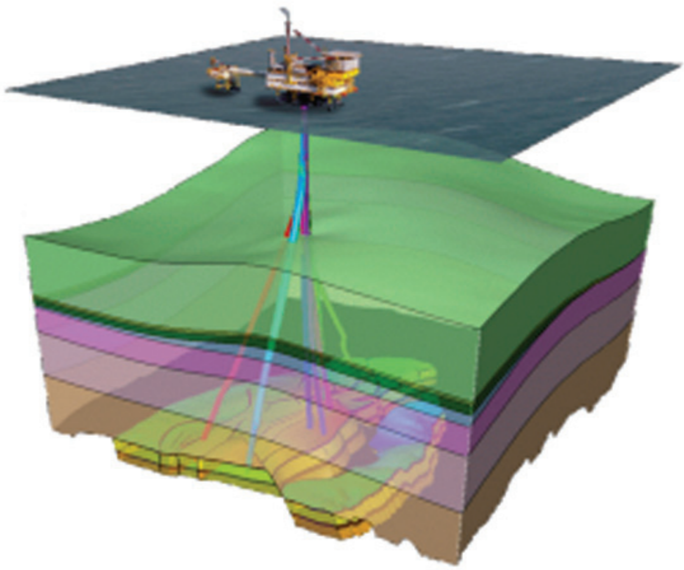

Carbon capture and storage has the potential to be the size of North Sea oil and gas industry and be worth more than £2bn/yr and sustain more than 30,000 jobs by 2030. North Sea CO^2 storage space is estimated at more than 22 billion tonnes which is 180 years' emissions from the UK's 20 largest point sources. But what are the geological factors affecting how this space can be used? How will geology inform the regulators and the public and what are the risks and opportunities for the private sector?

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cal's pilot using amines, we started running the process in September on line one and it is running well. We have installed some modifications which were always planned. We deliberately delayed them because we wanted to run the process in a more conventional manner, and now we've made some proprietary modifications and the results are very good and we're pleased enough that we've got a contract with Archer Daniel Midlands which will develop into building a facility that will involve storing something of the order of two million tonnes of CO_2 per year in the Illinois basin.

"We also have a contract in Canada, the Pioneer project, co-funded by the Alberta and Canadian governments, to build a 250MW capture system for TransAlta."

"We have everything in place to commercialise the technology by 2015," concluded Mr. Hilton. "I think we'll do a couple more of these demonstration plants, particularly I suspect we'll do one in China."

He went on to talk about the challenge of ramping up the technology after 2015. "I think we can do this. When we went into the NOX wave in the US in 1999 everyone said it couldn't be done and we did more than 100GW in four years."

"I tend to think that as an industry we get things done and I think that CCS won't be an exception. We are talking about delivering after 2016 and as an industry we have time to ramp up and we'll do the right things in terms of training, and facilities and realising the size of the market."

Pilot results at Pleasant Prairie

The project at We Energy's Pleasant Prairie plant was a field pilot designed to validate proof of concept. It captured approximately 40 tons of carbon dioxide each day, and proved that it is possible to operate a chilled ammonia carbon capture system on the flue gas from an operating power plant.

In early 2006, Alstom and EPRI set out to jointly develop a field pilot to demonstrate the chilled ammonia carbon capture process. EPRI's support was provided through 37 U.S. and international members who formed a collaborative, which not only helped to offset the costs of the project but also gave power generation owners and operators an inside look at a promising new technology under development.

Alstom and EPRI first conducted a comprehensive screening process to select a plant suitable to host the field pilot. From among several candidates, they chose the We Energies Pleasant Prairie Power Plant ("P4 Plant"), a state-of-the-art power generation facility that operates with extremely high environmental performance.

Units 1 and 2 were retrofitted with selective catalytic reduction (SCR) systems to control emissions of nitrous oxides (NO_x) and wet flue gas desulfurization (FGD) systems to control sulfur dioxide (SO_2) emissions. This retrofit also included the construction of a new chimney.

The chilled ammonia pilot system withdraws about 1 percent of the flue gas between the outlet of the Unit 1 or Unit 2 FGD and the stack. The gas is first cooled to condense and remove moisture and residual pollutants before it enters the CO_2 absorber. There, the CO_2 is absorbed by an ammonia-based solution, separating it from the flue gas, and heated releasing a very pure stream of CO_2.

The CO_2 is remixed with the treated flue gas after sampling measurements and the entire extracted gas volume then is reintroduced into the FGD outlet transition duct where it is mixed with the FGD exhaust gas. At maximum capacity, the pilot system has been designed to capture nearly two tons CO_2/hour (equivalent to 15,000 tons/year at full capacity).

Lessons learned

The field pilot at Pleasant Prairie was the first opportunity to test different unit operations as a fully integrated process in a continuous mode, capturing CO_2 from actual flue gas. It took several months of work to resolve the various issues that arose during initial operations. However, after some initial modifications to the process design, the project achieved most of a series of operational objectives and met the fundamental research objectives.

Objectives

1. Demonstrate full system operation on flue gas from a coal-fueled boiler, including: flue-gas cooling using heat recovery/exchange and chilling; removal of residual pollutants; CO_2 separation from the flue gas (absorption by the ammonia solvent); and production of high-purity CO_2 and regeneration of the solvent.

Results: Over time, pilot performance steadily improved to the point that stable absorber operation at 100% of design flue gas flow was established in April 2009. From this point, the pilot has demonstrated the ability to meet all the key performance metrics in this objective.

2. Prove the process concept:

• High-efficiency removal of CO_2 (> 90%)

• Minimize ammonia slip (release) (< 5ppm)

• Produce high-purity CO_2 which can be re-used or safely stored underground

Results:

• CO_2 removal - Demonstrated > 90% CO_2 removal at design conditions

The pilot plant at We Energy's Pleasant Prairie plant in Wisconsin

• Ammonia release - During operations at design gas flow, we have consistently measured less than 10 parts per million (ppm) and normally less than 5 ppm ammonia released

• CO_2 purity - Produced high-purity CO_2 with low ammonia (< 10 ppm) and water content (< 2,500 ppm); other impurities require further testing/ evaluation.

3. Begin to identify operational procedures for routine operation, startup and shutdown, and begin to establish system reliability.

Results: The pilot has operated for more than 7,000 hours and, since September 2008, it has reliably operated 24 hours per day, 7

days per week. During this period, there were only two unplanned outages for pilot plant maintenance.

The experience in operating the field pilot has been invaluable, as the Alstom operations and project validation teams have refined startup and shutdown procedures and gained experience troubleshooting issues with process operation.

Validation of the total energy consumption of the process was not a key objective of this project. This is because total energy consumption can only be validated on an efficiently designed system that is demonstrated at a commercial scale and fully integrated with the power plant. However, the heat of reaction and heat of vaporization, which are dictated by the process chemistry, could be validated at the pilot scale.

Alstom and EPRI were interested in measuring the energy consumption of the process, comparing the results with initial estimates, and incorporating the data into techno-economic studies that estimate the total energy consumption for a commercial scale process.

The team collected empirical data for these two key parameters driving energy consumption, and compared the data to original Alstom estimates.

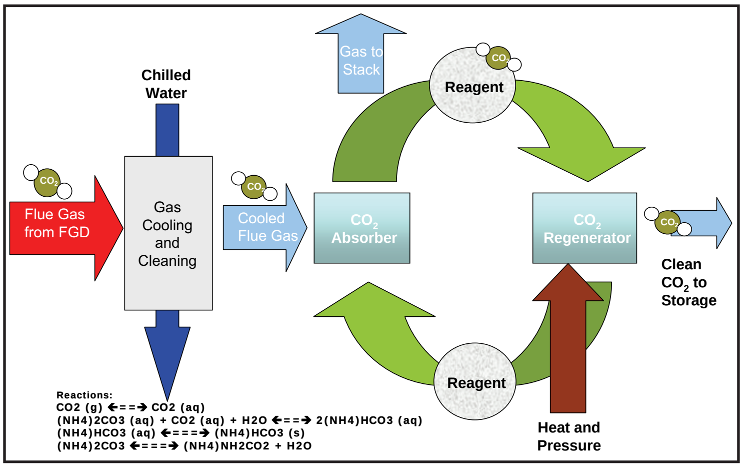
The results: these values compare favorably with values determined in the laboratory setting; the results validate the figures used to size the validation pilots; the results validate the figures being used in commercial feasibility studies.

The fundamental lesson learned at Pleasant Prairie was that it is possible to operate a chilled ammonia carbon capture system on the flue gas from an operating power plant and in a typical plant environment. The project achieved the vast majority of its research objectives and demonstrated the fundamental viability of carbon capture by this process.

Technology that worked in laboratory experiments proved viable in real-world conditions like hot and cold weather, the inevitable starts and stops of a large power plant, and the environmental challenges that go along with using any chemical process. Moreover, the project achieved key research metrics around hours of operation, ammonia release, CO2 removal levels, and CO2 purity.

The few objectives that weren't completely accomplished can be addressed more effectively in later stages of the R&D cycle. For example, key questions around energy consumption – a key driver of cost – and other important technical issues will be addressed as larger-scale demonstrations work to fully optimize the technology.

What's next?



Alstom's Chilled Ammonia process

The R&D process for carbon capture technologies is expected to move through progressively larger stages designed to validate different issues, with a goal of optimizing the technology before it is brought to market.

EPRI is supporting Alstom and AEP on the next phase of demonstrating the chilled ammonia technology pioneered at Pleasant Prairie. That project is the first to capture CO2 from a pulverized coal-fueled power plant and inject it into a permanent storage site, more than 8,000 feet underground. The data collected and analyzed by that collaborative will support efforts to advance CCS technologies to commercial scale and provide information to the public and industry on future advanced coal generation options.

A 20-megawatt electric capture system has been installed at AEP's 1,300-megawatt Mountaineer Plant, where it will remove up to 110,000 tons of CO2 emissions annually from the flue gas stream of the plant. The captured CO2 will be compressed, transported by pipeline and injected into two saline reservoirs located under the plant site.

The project has just received funding through the Clean Coal Power Initiative (CCPI) Round 3 for scale up of the CO2 capture systems to commercial-scale. A 235-MW slipstream at Mountaineer Plant will be used to capture ~1.5 million tonnes of CO2 per year which will be injected into saline formations near the site.

Alstom is also developing a third and final phase commercial-scale demonstration project, the Pioneer Project, that will be designed to capture between 1.0 – 1.5 million tons of CO2 per year. Alstom currently is working with AEP, TransAlta, a Canadian energy company, and other parties to successfully develop this demonstration project.

Alstom has committed to have a commercial offering for a carbon capture technology available by 2015 and believes the progress made at Pleasant Prairie keeps it on track to meet that commitment.

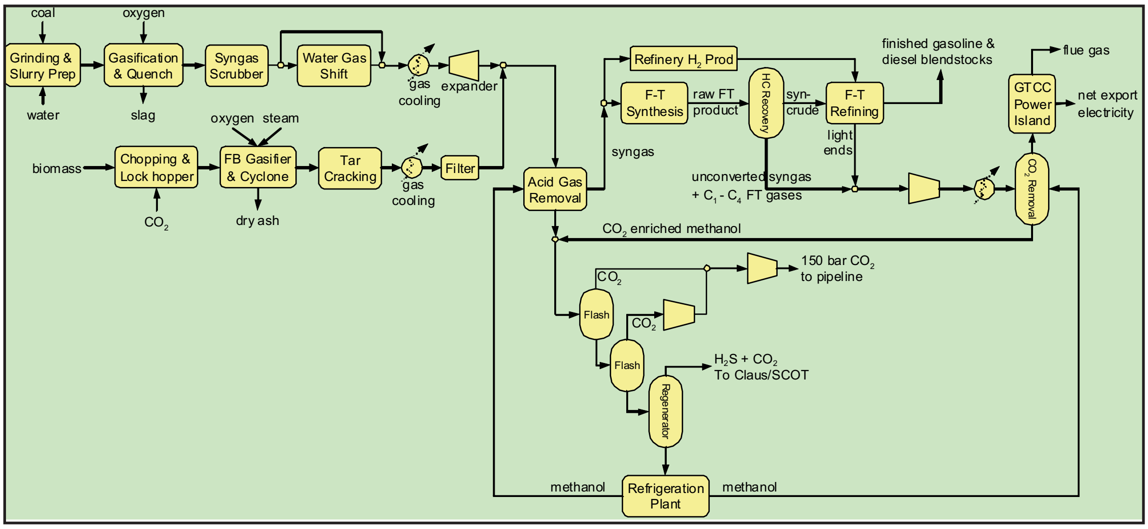
The chilled ammonia pilot at AEP's Mountaineer Plant in West Virginia

CCS for coal power plant sites with low energy and cost penalties

Robert Williams, Senior Research Scientist with the Princeton Environmental Institute at Princeton University (USA) has estimated that the overall energy penalty of coal carbon capture and storage could be reduced to 7 per cent (instead of approximately 36 per cent for a carbon capture and storage unit retrofitted to a traditional pulverised coal plant).

The strategy he proposes would also actually take carbon dioxide out of the atmosphere, provide extra clean vehicle fuels and thereby reduce the need for coal-rich countries to import oil, reduce the amount of water required for energy production, and provide decarbonized electricity at very attractive costs in a world of high oil prices.

He was speaking at the December 9th conference "Which Technologies to Diversify Transportation Fuels?" organised by IFP in Paris.



Coal and biomass to finished Fischer-Tropsch Liquid (FTL) fuels and electricity with once through (OT) synthesis and CCS system for making electricity +synfuels from coal + biomass

In order to decarbonize coal power, Williams suggested that instead of retrofitting the old existing coal power plants with CCS equipment, these old plants should be scrapped and replaced at the same site with new plants that make synthetic liquid fuels (~ 2/3 of energy output) as well as electricity (~ 1/3 of energy output)—as a "repowering" option for existing coal power plant sites.

These new plants would gasify the feedstocks to make synthesis gas (mostly carbon monoxide and hydrogen). Then the H2/CO ratio for the synthesis gas would be increased in a water-gas-shift reactor. The shifted synthesis gas would then be fed to a synthesis reactor where Fischer-Tropsch liquid fuels are made. And finally the synthesis gas unconverted in a single pass through the synthesis reactor would be burned to make electricity in a combined cycle power plant.

Carbon dioxide generated in the gasifier, the water-gas-shift reactor, and the synthesis reactor (accounting for about ½ of the carbon in the feedstocks) would be captured at high partial pressures from synthesis gas streams both upstream and downstream of synthesis, pressurized, and delivered via pipelines to geological storage sites.

The plants Williams proposes would use as feedstock biomass as well as coal in order to realize deep reductions in GHG emissions—with separate gasifiers for each feedstock. For these systems the overall greenhouse gas emissions would be lower, the greater the biomass input percentage. Most of his remarks were focused on plants that would reduce greenhouse gas emissions more than 90%—in which case biomass would have to account for 35-40% of the feedstock energy input.

In a comparison of several alternative options for decarbonizing existing coal power plant sites Williams showed that the least capital-intensive option involves keeping the existing plant but adding new equipment that would capture CO2 from the flue gases for geological storage. These flue gases contain only about 15% CO2 so that the CO2 must be captured at the very low partial pressure of 0.15 atmospheres.

Capturing the CO2 from such a dilute gas stream requires use of a very strong chemical solvent, the regeneration of which requires considerable energy. For the overall system Williams estimated that the energy required per MWh would rise 36% and that the water requirements for the site would increase 33%.

Among the various "repowering" alternatives to this retrofit strategy examined, the most attractive option Williams identified under a serious carbon mitigation policy would be those systems coproducing liquid fuels and electricity with CCS using as feedstock coal and enough biomass (35-40%) to reduce GHG emissions more than 90%.

The major drawbacks of these coal/biomass coproduction with CCS repowering systems are that: (i) the capital cost would be ~ 3X that for the CCS retrofit, and (ii) the cost of delivered biomass (on a $ per GJ basis) would be ~ 3X that for delivered coal. But the energy penalty for CCS would be only 7%, and the water requirement for the site would be reduced 19% from the level for the original coal plant.

The levelized cost of electricity generation including the cost of GHG emissions is perhaps the best single performance index for comparing options. The generation cost for the CCS retrofit option becomes less than for the displaced written-off coal plant only for a GHG emissions price greater than $75 per tonne of CO2eq ($/t). The generation cost for the coal/biomass coproduction with CCS repowering alternative depends on the oil price—but would typically be much less

than for the CCS retrofit option.

At a GHG emissions price of $75/t and an oil price of $100 a barrel (which many believe will be a typical oil price post-2020) the generation cost would be 70% less than for the CCS retrofit and no higher than the generation cost for the written-off coal power displaced at $0/t. Even if the world oil price were to collapse to $50 a barrel, the generation cost would still about 10% less than for the CCS retrofit when the GHG emissions price is $75/t…showing that a strong carbon mitigation policy would protect investors in such coal/biomass coproduction with CCS plants against the risk of oil price collapse.

So how is it that systems requiring 3X the capital of CCS retrofits and for which the delivered biomass is estimated to cost 3X the cost of delivered coal come out looking so attractive economically? One reason is that substantial streams of pure CO2 are always generated as an intrinsic feature of the synthetic fuels manufacturing process; capturing these pure CO2 streams is relatively cheap—essentially the cost of CO2 compression.

Another reason is that the efficiency and capital cost for making the electricity coproduct of a coproduction system are much less than for stand-alone power plants. A third reason is that if there is a price on GHG emissions, systems that store photosynthetic CO2 get credit for negative CO2 emissions—in this case representing about ½ of the carbon in the biomass feedstock. A fourth reason is that production costs for the synthetic fuel coproducts will tend to be less than their market value in a world with prospective high oil prices.

This low GHG-emitting coal/biomass coproduction with CCS strategy can be pursued only to the extent of the available biomass supplies. In light of growing concerns about conflicts with food production and the land-use impacts of growing biomass on cropland, biomass supplies that can be provided sustainably are likely to be limited mainly to agricultural residues (such as corn stover and wheat straw), various forest residues, municipal solid wastes, and dedicated energy crops that can be grown on lands that are not suitable for growing food.

For the US this implies that prospective biomass supplies are less than 40% of what was thought to be available just five years ago. Nevertheless, this amount of biomass (~ 0.5 billion tonnes per year) would be adequate to displace about 90% of current coal generating capacity in the United States.

The low-GHG-emitting liquid fuel coproduct would be produced at a rate of almost 4 million barrels per day (gasoline equivalent)—enough to support all future US light-duty vehicles and more that 1/3 of fuel for air transportation if, under a serious carbon mitigation policy, automotive fuel economy were to rise to a future norm equivalent to that for 2030-version of a mid-sized hybrid-electric car (76 mpg or 3.1 liters/100 km).

If the energy input level for a repowering system is the same as for the old coal power plant displaced, the amount of decarbonized electricity generated would be about 40% less than the generation level for the original plant. So a large amount of makeup power would be required—considerably more than the 15% makeup power that would be required if the CCS retrofit were adopted instead.

In a comparison of these two alternative paths for decarbonizing 90% of current US coal capacity, Williams showed that the repowering strategy would provide 1.5 X as much reduction in GHG emissions, require 0.85 X as much CO2 storage, and use 0.9 X as much coal as the CCS retrofit strategy. In both instances he assumed that coal IGCC-CCS systems with 90% capture would be used to provide 100% of the makeup power,

Williams proposes that the repowering effort be carried out over a period of a couple of decades after the technologies are demonstrated at commercial scale during the coming decade. First generation plants that could be built for commercial-scale demonstration during the coming decade would use much less biomass (~ 10%) but would still be able to realize GHG emission rates that are about ½ of the rate for the conventional fossil fuel energy displaced. Several such demonstration projects would be strong candidates to be included in the 20 commercial-scale integrated CCS projects that the G-8 has agreed to sponsor worldwide during the coming decade under its Global CCS Initiative.

Aside from the need for: (i) these commercial-scale demonstration projects, (ii) establishing the viability of CCS as a major carbon mitigation option (e.g., via the G-8 Global CCS Initiative), and (iii) a public policy that puts a price on GHG emissions, there are no significant technical or economic barriers to deployment of coal/biomass coproduction with CCS systems.

But there are institutional obstacles arising from the need to manage simultaneously three commodity products (liquid fuels, electricity, and CO2) that serve very different markets and two very different inputs (coal and biomass). Who would own and operate such systems? Would industrial partnerships between oil and power companies be a viable approach? Or would coal companies lead in deploying these technologies?

New public policies are needed to overcome these institutional obstacles to the deployment of these coproduction systems—just as in 1978 a US law (The Public Utility Regulatory Policies Act) was passed that overcame the institutional obstacles to deployment of combined heat and power systems.

Potential impacts of GCS to underground sources of drinking water

Working together, the water and geologic carbon sequestration (GCS) industries have the potential of arriving at solutions to reduce CO2 emissions without harming present and future water supplies.

By John Largey MWH Americas, Inc. and Neil Johnson MWH Americas, Inc.

Regulatory Environment

In the United States, over 150 million people rely on groundwater as the source of their drinking water[1]. The Safe Drinking Water Act (SDWA) was passed by Congress in 1974 to protect public health by regulating the nation's public drinking water supply.

It gave the United States Environmental Protection Agency (EPA) the authority to regulate underground injection and led to the development of the Underground Injection Control Program (UIC) to protect underground sources of drinking water (USDWs). EPA's authority to regulate the geologic storage of CO2 was clarified under the Energy Independence and Security Act of 2007, which stated that all regulations must be consistent with the requirements of the SDWA.

On July 25, 2008, the EPA proposed draft Federal requirements under the SDWA for underground injection of CO2 for the purpose of geologic carbon sequestration (GCS). The proposed rule focuses on protecting USDWs and is based on existing UIC regulations with modifications to address the particular aspects of CO2 injection for GCS.

The UIC program establishes permit conditions that govern design, construction, operation, inspection, and monitoring requirements for five classes of injection wells. The injection of fluids for enhanced oil and gas recovery (EOR) has been a long-standing practice within the UIC program. These wells are designated as Class II wells and include wells injecting CO2 for EOR purposes.

Pilot and experimental wells injecting CO2 are generally regulated as Class V experimental technology wells. Under the proposed regulations, injection wells permitted for GCS would be regulated as a new category of injection well designated as Class VI. Key differences taken under consideration for GCS applications include large volumes of CO2, larger scale projects, the relative buoyancy of CO2, the resulting fluid corrosivity, the potential presence of impurities in captured CO2, and its mobility within subsurface formations.

The EPA has defined USDWs as underground aquifers with water having less than 10,000 mg/L total dissolved solids (TDS) concentrations and which are capable of supplying a sufficient quantity of groundwater to supply a public water system. The use of new treatment technologies and increased water supply needs has increased the use of aquifers with TDS greater than 10,000 mg/L.

The practical upper limit of TDS for a water source can exceed 10,000 mg/L depending on site-specific conditions. In fact, some communities currently use water sources with raw water TDS concentrations much greater than 10,000 mg/L. It has been suggested that the 10,000 mg/L TDS limit for classifying USDWs for the siting of Class VI wells needs to be revised upward to include aquifers with TDS concentrations greater than 10,000 mg/L.

Geologic Sequestration in Saline Aquifers

Saline formations make up about 90 percent of the potential storage capacity for CO2 sequestration[2]. In the past, there has been little interest in studying and characterizing these formations. There is little information about the chemical and physical characteristics of most saline formations considered as candidates for CO2 injection.

Injected CO2 is sequestered by a combination of one or more mechanisms such as structural, stratigraphic, hydrodynamic, and geochemical trapping. Potential risks from GCS primarily result from the consequences of unintended leakage of CO2 from the storage formation into overlying aquifers. If these other aquifers are underground sources of drinking water (USDW), the potential exists for the CO2 to affect the water quality characteristics, possibly posing a threat to water resources.

For example, the evaporative processes that create saline formations can result in elevated concentrations of potentially toxic elements and compounds. The potential for GCS to cause changes to water quality is a concern to the American Water Works Association (AWWA) and the Association of Metropolitan Water Agencies (AMWA). Together, these two organizations represent drinking water utilities of all sizes that serve more than 90 percent of the U.S. population.

Water Industry Research

In order to better understand potential consequences that GCS may have to the water industry the Water Research Foundation (WRF formerly AWWA Research Foundation or AWWARF) funded a research study of potential impacts to groundwater supplies titled Potential Groundwater Quality Impacts Resulting from Geologic Carbon Sequestration[3].

This recently published study was performed by MWH Americas, Inc. (MWH) and Schlumberger Water and Carbon Services (Schlumberger). The objectives of this study were to document and assess the technology and understanding of the GCS process, identify and characterize potential impacts of GCS on the quality of groundwater supplies, review existing approaches and recommendations for assessing and mitigating these impacts, develop a monitoring guideline, and perform a comprehensive evaluation of this information in order to ascertain knowledge gaps and identify future research priorities

Potential Pathways

There are several potential scenarios by which a USDW may be impacted by GCS activities. Potential pathways are presented in Figure 1 and include upward migration, fractured cap rock, faults, trace contaminants included in the CO2 stream, a microannulus outside the final casing, and the mobilization of metals from native minerals

The success of GCS relies on the structural integrity of confining units, for trapping CO2 in underlying permeable formations. Injection of CO2 into the receiving aquifer has the potential to cause deformation, trigger seismicity, reactivate faults, and compromise seals in wells. Each of these processes could increase the risk of leakage jeopardizing containment and the protection of groundwater quality.

1 Andrew W. Stone, American Ground Water Trust, Concord, NH 03301, USA Ground Water For Household Water Supply In Rural America: Private Wells Or Public Systems? Paper presented at the Joint Conference of the International Association of Hydrogeologists and the American Institute of Hydrology, Las Vegas, September 1998 and published in the Proceedings

2 DOE 2007 Carbon Sequestration Atlas of the U.S. and Canada. U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Office

3 Water Research Foundation 2009 Potential Groundwater Quality Impacts Resulting from Geologic Carbon Sequestration, 2009, Principal Investigators: John Norton, Chris Petersen, Thomas Berard, Timothy K. Parker, L. E. (Ted) Eary, John Largey, Andrew Duguid, Aya Lamei, Claude Roulet, Suzanne K. Mills, Neil Johnson, Guillemette Picard, and Marcia Couselan ISBN: 978-1-60573-060-8

The capacity of a geologic formation for CO2 injection depends on the formation geohydraulic properties, including porosity, hydraulic conductivity, permeability, as well as the viscosity, chemical composition, and density of the fluid contained in the pore spaces of the formation. Pressure from injection of supercritical CO2 will decrease radially away from the injection point. The extent of the pressure increase will depend on the permeability and hydraulic communication of the storage formation with the surrounding formations. The resulting pressure buildup could be insignificant and dissipate quickly, or could be larger and persist for millennia.

The injection of CO2 also sets in motion a series of geochemical processes that have the potential to change water chemistry in a receiving formation. If pathways from the receiving zone to other geologic formations, such as those containing USDWs exist, these same types of changes could potentially alter the USDW's water quality.

Other important processes include displacement of USDW water with more saline water from the injection zone. This could result in increases of total dissolved solids (TDS) and salinity, decreases in pH mobilizing metals, and increases in dissolved organic carbon causing a deterioration of the USDW's water quality. Other effects may include increases in alkalinity, increases in dissolved silica, and changes to microbial populations.

The solvent properties of supercritical CO2 are known, but the WRF investigation revealed that the effects on water quality during CO2 injection have not been a research focus. Elevated metal concentrations have been observed in experimental and field tests of CO2 injection, and are attributed to the resulting acidification caused by high CO2 partial pressures in injection zones.

A better understanding of the potential for mobilization of metals and organic compounds by supercritical CO2 and their transport into USDWs is needed. Metal leaching and transport could affect water quality in systems where fluid movement into adjacent aquifers is possible.

Purveyors of water are not only concerned about gross contamination of drinking water aquifers, but also the potential of GCS to impact the existing water quality of other USDWs. Today's groundwater treatment facilities are designed and constructed to treat water supplies with specific water quality parameters.

Reverse osmosis, microfiltration and nanofiltration treatment regimes rely on source water with stable water quality parameters. Small changes to the groundwater source chemistry and quality parameters such as salinity, total dissolved solids, silt density, pH, and metals content may require significant and costly modifications to the operating procedures or the physical plant to be made.

Enhanced Oil Recovery

Of particular interest to AMWA and AWWA is the potential for the construction of injection wells for EOR purposes. As previously mentioned, EOR wells are regulated as Class II injection wells. Class II EOR wells have much less stringent permitting, construction, monitoring, and mechanical integrity testing requirements than the proposed Class VI GS regulations.

The organizations' concerns include uncertainties associated with "grandfathering" Class II wells lacking specific Class VI design and construction criteria for GCS use. Conversion from Class II to Class VI would also place responsibility for the sequestration phase on the owner.

This may be outside the owner's expertise or interest. These organizations have also expressed concerns that parties may design and operate the system as a Class II facility before converting it to a GCS only facility and could, in effect, bypass some of the stringent Class VI requirements.

Risks

Risk is typically defined as the product of the probability of occurrence of an event and the negative consequence of the event. There are concerns that there is limited likelihood data concerning the consequences of GCS, which might result in either over or underestimation of chances of occurrence. Water purveyors take pride in meeting their mandate to protect the public health by providing safe clean drinking water.

While the probability of a USDW being significantly impacted may be low, the negative consequences of any such incident have the potential to be very high. The proposed rule requires operators of GCS facilities to provide financial assurances adequate for corrective actions, plugging and abandonment of wells, post injection site care and closure, and emergency response for failed injection wells. The question of how to structure liability for long-term risks to USDWs associated with the geologic sequestration of CO2 has not yet been resolved.

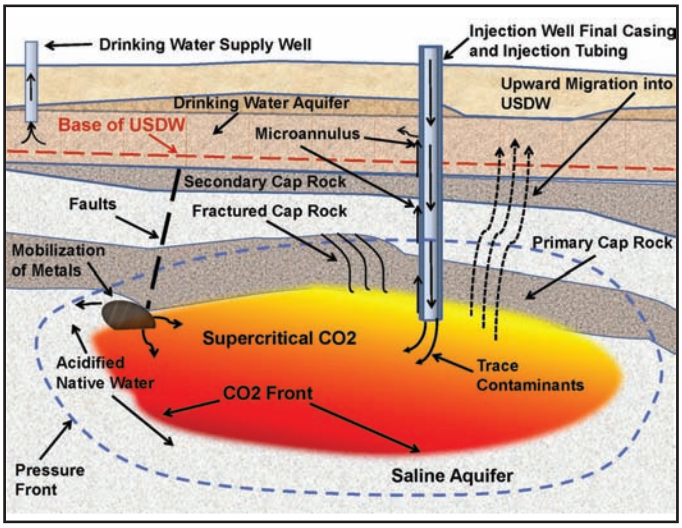


Figure 1 - Potential pathways of water contaminationby CO2

Working Together

Available information indicates that large scale GCS operations can be conducted with low risk of impacting USDWs when carried out at well-selected, well investigated and well-managed sites. Drinking water providers understand that rapid climate change is a serious issue that requires innovative solutions. However, these water providers are also concerned that implementation of large scale GCS facilities without proper science may have unintended harmful consequences to present and future USDWs.

The recently published Water Research Foundation report Potential Groundwater Quality Impacts Resulting from Geologic Carbon Sequestration indicates an active willingness by the water industry to increase their knowledge and understanding of GCS. Confidence in the implementation of GCS projects may be enhanced by encouraging the participation of water providers in the development of site characterization, risk assessment, and monitoring guidelines.

Working together, the water and GCS industries have the potential of building a better world by arriving at solutions to reduce CO2 emissions without harming present and future water supplies.

More information

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CCS in Central Appalachia

What would CCS in Central Appalachia look like and how is it possible that one could arrive at a successful implementation?

By Steven M. Carpenter, Director of Carbon Management & Corporate Risk Manager, Marshall Miller & Associates

In general terms, carbon capture & storage (CCS) is a three pronged technology that addresses most every issue between the source of the carbon emission and sink (or storage) of the CO2. Based on recent research and pilot/demonstration programs, most experts agree that the potential for full scale CCS is both possible and required. The capture technology at the plant level is further advanced and is less constrained by the location of both the source (facility) and the sink than are the remaining two aspects - transportation and storage.

Carbon transport and storage in the coal region of Central Appalachia posses several unique issues within this three-pronged approach. In particular, transportation and storage pose significant impediments to the advancement of the technology and more importantly to the implementation and full-scale deployment of its use.

Quite simply, no CO2 (or Enhanced Oil Recovery) pipeline infrastructure exists in Central Appalachia. Open Congressional Research Reports for the People reported in Pipelines for Carbon Dioxide (CO2) Control: Network Needs and Cost Uncertainties that then President Bush would require "the Secretary of the Interior to recommend legislation to clarify the issuance of CO2 pipeline rights-of-way on public land.

The cost of CO2 transportation is a function of pipeline length and other factors. This report examines key uncertainties in CO2 pipeline requirements for CCS by contrasting hypothetical pipeline scenarios for 11 major coal-fired power plants in the Midwest Regional Carbon Sequestration Partnership region. The scenarios illustrate how different assumptions about sequestration site viability can lead to a 20-fold difference in CO2 pipeline lengths, and, therefore, similarly large differences in capital cost."

These differences (or increases) have significant impacts on financing, ownership, constructability and therefore full scale deployment of the required CO2 pipeline infrastructure. Additionally, higher CO2 transportation costs in "sink-poor" geological regions will lead to regionally higher energy costs.

To date, most CO2 transportation has occurred in existing EOR pipeline infrastructure. The map (provided by the European Energy Forum) illustrates the enhanced oil recovery (EOR) pipelines in the US that are available for use as CO2 transportation infrastructure. It is readily apparent that no infrastructure exists in the Central Appalachian coal region.

Once the impediment of getting the CO2 from the source to the sink is addressed, the next issue to tackle is that of the "sink" or storage field. It is hard to argue with Mother Nature. Large, deep saline sinks are where they are, and conversely, aren't where they aren't. It is impossible to ignore the lack of deep sinks in the hard rock northeastern U.S.

This unfortunate scenario also applies to the coal fields of Central Appalachia. Most of the geological data in Central Appalachia is from formations less than 4,000 feet deep. Knowing that little to no coal exists below that depth, little data exists. This issue is compounded by the fact that due to the proximity of the coal, many coal-fired power plants are located in the Central Appalachian basin to take advantage of mine-to-mouth's lower coal transportation costs.

Along with the Midwest Regional Carbon Sequestration Partnership, the Southeast Regional Carbon Sequestration Partnership (SECARB), managed by the Southern States Energy Board, is providing research and development in the CCS arena especially in the Central Appalachia region. The SECARB Partnership manages four projects in the Appalachian coal basin. In simplest terms: Deeper is better. The lack of deep options coupled with a significant number of coal-fired power plants creates what some are calling the "Perfect Storm" of significant need and significant lack of availability of carbon sinks in the region.

Reverting back to the Mother Nature reference, sometimes the requirement is to take what is available, and make it work. To that end, research performed by Marshall Miller & Associates through SECARB under funding by U.S. DOE contract DE-FC26-04NT42590, several storage field options have been identified. The key issue is depth versus breadth. There exists much "shallow" (less than 4,000 feet) geological data. Based on that data, one potential storage area has been mapped in southwestern Virginia. According to the DOE Carbon Sequestration Atlas, the Central Appalachia area of SECARB contains the second-largest

US enhanced oil recovery pipelines available for use as CO2 transportation infrastructure (Source: European Energy Forum)

concentration of thin, unmineable coal seams. These seams have an estimated storage capacity that ranges between 60-90 billion tons/ CO2 storage.

Data derived from SECARB's research indicates that the capacity does in fact exist. The following isometric storage potential map of two local power plants (AEP-Clinch River and Dominion-Virginia City Plant) shows the potential for 100 years of 100 percent CO2 emission storage, assuming 100 percent carbon capture was achievable.

The great news is that storage capacity exists. The bad news, accessing that capacity may prove to be difficult. Again, referring to the deeper is better adage, the more shallow a storage field is, the broader or larger "footprint" the storage field will encompass. The general understanding in the CCS industry is that the oil and gas scenario of forced pooling and unitization of property rights to incorporate storage fields will be applied to the carbon aspect of a storage field. As an example, a typical natural gas storage field in northern West Virginia is approximately 14 square miles or 8,960 acres. Based on the "broader" footprint of a carbon field, the needed area could grow to as large as 50 square miles.

This is where the lack of standardized regulations leaves the door open for some interpretation and "philosophizing." In the U.S., the basis for CCS is derived from the 2007 Supreme Court decision in Massachusetts v EPA, where the court gave the EPA the right to regulate carbon dioxide under the Clean Air Act as a pollutant. The legal basis for the oil and gas industries "forced pooling and unitization" is based on the fact that natural gas stored underground is an asset. And as such, a landowner is compensated for the "use" of the land via a royalty payment.

The Massachusetts v EPA case, in my opinion, opens the door to the use of forced pooling and unitization except in this application, carbon, it is a liability or a "pollutant" under the law. That subtle nuance, changes the royalty game into a liability game.

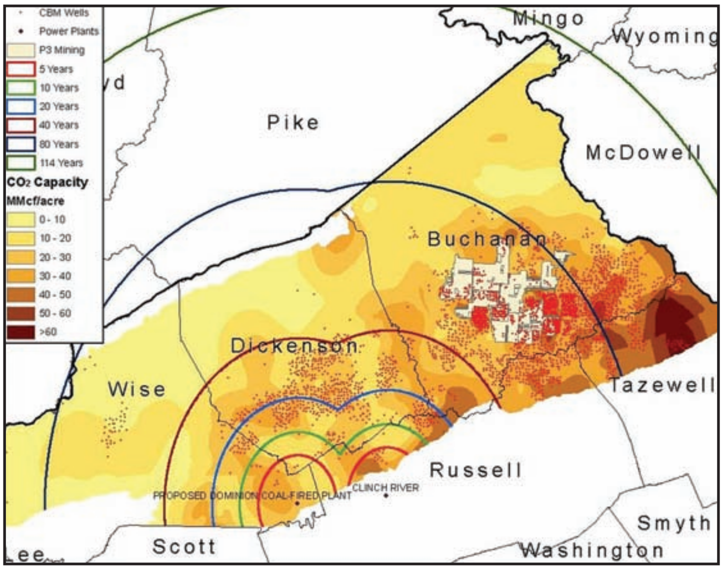
Here is what I mean: In the absence of some form of federally regulated insurance or risk and liability pool, say similar to the Price-Anderson Act relative to nuclear power plant construction and operation, there is no limit to the "fee" or price someone can demand to accept the liability of carbon stored on his or her property. As in the case of natural gas, the gas is a commodity asset and the price is fixed by an outside entity.

If carbon dioxide is forced into the ground on property owned by someone who doesn't want it stored there, here is how I see the math working out: Typical to West Virginia, a 50-square-mile tract of land could contain on average 1,250 parcels. Assuming one surface right owner and the potential for two subsurface rights owners (coal, gas and or pore space) = 3,750 liability negotiations. Now is where the nuance gets exponential. Instead of being paid a flat fee or percentage, say 12 percent in normal gas operations (as an asset) the land/mineral right owner can name their price for the liability being placed underground (e.g. CO2). So, take the 3,750 potential property rights holders and multiply them by $100,000/each or $1,000,000 each or higher. Very quickly the cost to secure the property rights for one 50-square-mile storage field becomes so large that it has the effect of not being real money (e.g. Monopoly® money). At a million dollars each (for the liabilty assumption) this "one field" would cost $3.75 bilion just of the liability rights.

The use of these shallow, unmineable coal seams present another potential impediment to carbon storage. Because the sinks are shallow, the CO2 is stored at a non-supercritical state. This creates a volume issue in that the deeper saline formations are at such a depth that the CO2 stored will be at a supercritical state, thus providing an order of magnitude greater storage capacity, simply due to the depth (and therefore pressure) at which the CO2 is stored. The chart below indicates graphically the relative size of CO2 at storage depth.

Let's assume for the sake of discussion, that the issues of transportation and storage can be addressed. What other impediments stand in the way of full-scale commercialized CCS in Central Appalachia (aside from carbon capture at the plant level)? Unfortunately there are several: cost (DOE vs. industry share), parasitic load for carbon capture at the plant level, risk and liability, and monitor, verify and account.

Cost share from U.S. DOE is at a minimum $1 (DOE) per $1 invested (industry). In many cases, the required industry cost share is higher. The latest round of projects funded under DOE's Clean Coal Power Initiative (CCPI) Round III, included cost share from industry that was almost 3:1, that is industry invested $3 for every $1 provided by DOE. While having any funds to offset capital expenses, construction and or engineering costs is valuable, many publicly traded companies, in response to stakeholders and shareholders are receiving mixed signals - spend or not to spend - when to spend.



Isometric storage potential map of two local power plants (AEP-Clinch River and Dominion-Virginia City Plant) showing the potential for 100 years of 100 percent CO2 emission storage (Source: SECARB)

The parasitic load of the carbon capture equipment is very often not discussed. Estimates from Energy Information Agency suggest that to outfit the U.S. coal-fired fleet with full scale CCS would require 40 GW of parasite load – simply put, that is eight new 500 MW power plants to supply the energy needed to power the CCS system.

The risk associated with the previously mentioned asset versus liability discussion for property rights owners is a valid concern. Over half of the states have begun to put in place carbon laws and or programs that define, address and make it possible to address the liability issue of placing CO2 underground. These programs also aim to address the liability of the CO2 generator, specifically, who owns the CO2 once it is placed underground in storage. Is it the state, is it the generator or is it the storage operator?

MMV has become MVA. The DOE's mantra of "Measure, Monitor and Verify" has become "Monitor, Verify and Account." It is the last directive of "Account" that has provided some real issues or in the case of this article some real impediments to full scale implementation. Specifically, looking at the Central Appalachian region, there is a lack of homogeneity, time-in-grade and of standardization. As with most geology, Central Appalachia is not different. There is a general lack of homogeneity within seams that causes fractures, seeps, and "losses" that can't be "accounted" for very easily or, more importantly, in a cost effective manner, at least not yet. There is a lack of time-in-grade with CO2 being injected underground. Now I agree that CO2 has been used for EOR for several decades, but it has been used without regard to whether or not it stayed in place and whether or not, if it moved, how far it moved. These issues can't appropriately be addressed until there is an accepted (mandated and/or regulated) standard.

With all the hurdles to overcome, what would CCS in Central Appalachia possibly look like and how is it possible that one could arrive at a successful implementation?

The answer is: There is no silver bullet! There is; however, silver buckshot! We must change the paradigm and look at all options and consider all possibilities. We must not get mired in the old landfill-days-paradigm of Not In My Back Yard – NIMBY and prevent what Christopher Power of Dinsmore & Shohl's Natural Resources and Environmental Practice Groups calls "NUMBY" – not UNDER my back yard.

Ken Nemeth, Executive Director of SSEB and contributing author of From Energy Crisis to Energy Security sums it up succinctly. "The problems we confront are not insurmountable, but they are serious. … It is time for the political class to get serious about our access to energy". If we do that, the end result will be successful. Success is meeting the energy demand in a way that is cleaner, greener and sustainable.

More information

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TUV NEL seminar highlights technologies to achieve UK CCS goals

A recent Carbon Capture and Storage (CCS) conference, which was organised by TUV NEL, addressed the technological developments needed to put the UK and other countries on the path to achieving full-scale capture, transportation and storage of CO_2 emissions.

While the UK Government and various bodies are putting in place the necessary legal framework and financial incentives to accelerate the arrival of CCS, the conference, which was held on November 25, 2009 at Aston Conference Centre in Birmingham, brought together key industry players from each element of the CCS chain to discuss the challenges involved in taking CCS from a concept to a reality.

The technological needs required to take CCS forward was the key focus of the seminar sessions. The topical areas addressed at the seminar included:

- Pilot Plants: The latest development and learning from the CO_2 capture pilot plants
- Transportation: The practicalities and challenges associated with transporting CO_2 by pipeline and ship
- Measurement & Reporting: The needs and challenges associated with process and regulatory measurement throughout the CCS chain, from capture to injection into the storage formation
- North Sea Storage: The value, capacity and qualification of the North Sea for CO_2 storage
- Post Geological Monitoring: Ensuring the safe containment of CO_2 in the geological storage sites

The event was chaired by Lynn Hunter, who leads TUV NEL's CCS research activities.

According to Lynn, "The engineering infrastructure and building blocks necessary to take CCS forward will be on a scale never experienced before. The difficulties of handling such large volumes of CO_2 will present many unique challenges, which will have to be resolved in a timely manner should the timescales for CCS be met.

"The first priority will be to implement CCS in large-scale fossil fuel power stations. These alone account for over 30% of UK CO_2 emissions. Thereafter, it will be necessary to roll CCS out into other heavy CO_2 emitting industries. However, to date, CCS has not been technically proven on the scale required to take it forward to power stations, nor has the various elements of the CCS chain - capture, transportation and storage - been brought together and demonstrated."

Lynn Hunter, who leads TUV NEL's CCS research activities, working in the laboratory

One of the major challenges at present is the initial stage of capturing CO_2 from other flue gases before release into the atmosphere. There are three main technologies being looked at: post-combustion capture, pre-combustion capture and oxy-fuel capture, all of which are currently being developed and trialled in pilot plants around the world.

The second stage in the process also presents major challenges. This involves safely and economically transporting CO_2 to its final geological storage formation by ship, road and pipeline. The latter will rely on the development of suitable pipeline infrastructure spanning several hundred kilometres across land and sea. A number of UK pipeline network clusters have been proposed to serve the needs of the various power stations and heavy emitters.

The third stage in the CCS chain is the injection and storage of CO_2 into secure geological formations. Largely, this will entail storage in depleted oil and gas fields and in saline aquifers. Qualifying geological storage sites will be a critical part of the CCS process. The North Sea has been identified as having valuable storage capacity and is expected to become the CO_2 storage sink for Europe.

"Accurate monitoring and reporting will play a key role in the overall demonstration of CCS", said Lynn. "Measurement will be essential in order to control the CCS processes, to detect CO_2 leakage for environmental purposes and for verification under the EU Emissions Trading Scheme (ETS). These are also likely to present major challenges to industry, as reported in the study on Measurement Issues for Carbon Capture and Storage, produced by TUV NEL on behalf of the UK Government's National Measurement Office.

"Geological monitoring of the storage site will be necessary during and after injection to determine the fate of the CO_2 and to ensure its safe containment for many decades to come."

More information

TUV NEL is the custodian of the UK's National Flow Measurement Standards. As a leading international technology services organisation, TUV NEL has a successful track record of more than five decades delivering world class innovative solutions to difficult problems.

The company provides services, solutions and technology to clients across industries including oil & gas, government, manufacturing, renewable and sustainable energy.

www.tuvnel.com

Policy, company and regulation news

US DOE $3 Billion CCS investment

fossil.energy.gov

U.S. Energy Secretary Steven Chu has selected three new projects with a value of $3.18 billion to accelerate the development of advanced coal technologies with CCS.

An investment of up to $979 million, including funds from the American Recovery and Reinvestment Act, will be added to around $2.2 billion in private capital cost share as part of the third round of the Department's Clean Coal Power Initiative (CCPI).

The selections demonstrate technologies that:

* make progress toward a target CO2 capture efficiency of 90%;

* make progress toward a capture and sequestration goal of less than 10% increase in the cost of electricity for gasification systems and less than 35% for combustion and oxycombustion systems;

* capture and sequester or put to beneficial use an amount of CO2 emissions in excess of the minimum of 300,000 tons per year required by CCPI.

The Clean Coal Power Initiative Round III was created in 2005 to reduce the time it would take for low-emission coal technologies to be ready for commercial use. These awards are the second installment of projects awarded under CCPI Round III. Two projects were previously selected under CCPI Round III in July 2009 to receive $408 million in DOE funds.

The Clean Coal Power Initiative Round III selections announced are:

* American Electric Power Company, Inc. (Columbus, OH):

Project Title: Mountaineer Carbon Dioxide Capture and Storage Demonstration (see page 5 for details)

* Southern Company Services, Inc. (Birmingham, AL)

Project Title: Southern Company Carbon Capture and Sequestration Demonstration

Southern Company Services (SCS) will retrofit a CO2 capture plant on a 160 megawatt flue gas stream at an existing coal-fired power plant, Alabama Power's Plant Barry, located north of Mobile, AL. The captured CO2 will be compressed and transported through a pipeline, and up to one million metric tons per year of CO2 will be sequestered in deep saline formations.

Southern Company Services will also explore and use potential opportunities for beneficial use of the CO2 for enhanced oil recovery. In addition to SCS, the project team includes Mitsubishi Heavy Industries America, Schlumberger Carbon Services, Advanced Resources International, the Geological Survey of Alabama, EPRI, Stanford University, the University of Alabama, AJW Group, and the University of Alabama at Birmingham. (DOE share: $295 million; project duration: 11 years)

* Summit Texas Clean Energy, LLC (Bainbridge Island, WA)

Project Title: Texas Clean Energy Project (TCEP)

Summit Texas Clean Energy, LLC will integrate Siemens gasification and power generating technology with carbon capture technologies to effectively capture 90% of the carbon dioxide (2.7 million metric tons per year) at a 400 megawatt plant to be built near Midland-Odessa, TX. The captured CO2 will be treated, compressed and then transported by CO2 pipeline to oilfields in the Permian Basin of West Texas, for use in enhanced oil recovery (EOR) operations.

The Bureau of Economic Geology (BEG) at the University of Texas will design and assure compliance with a state-of-the-art CO2 sequestration monitoring, verification and accounting program. (DOE share: $350 million; project duration: 8 years)

The US Office of Fossil Energy's National Energy Technology Laboratory (NETL) database uses Google Earth to show a map of 192 proposed and active CCS projects worldwide

DOE - worldwide CCS projects on the increase

www.netl.doe.gov

Worldwide efforts to fund and establish CCS projects have accelerated, according to a new Department of Energy (DOE) online database.

The database indicates ongoing positive momentum toward achieving the G8 goal for launching 20 CCS demonstrations by 2010, according to the DOE.

The database, a project of the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL), reveals 192 proposed and active CCS projects worldwide. The projects are located in 20 countries across five continents.

The 192 projects globally include 38 capture, 46 storage, and 108 for capture and storage. While most of the projects are still in the planning and development stage, or have just recently been proposed, eight are actively capturing and injecting CO2:

* In Salah Gas Storage Project, Algeria

* CRUST Project – K12-B Test, The Netherlands

* Sleipner Project, Norway

* Snøhvit Field LNG and CO2 Storage Project, Norway

* Zama Field, Canada

* SECARB Cranfield, United States

* Weyburn-Midale, Canada

* Mountaineer CCS Project, United States

At its 2008 meeting in Japan, the G8 adopted a goal recommended by the International Energy Agency to launch 20 large-scale CCS demonstration projects globally by 2010, with a further goal of deploying these technologies by 2020. Worldwide efforts to fund and establish CCS projects in general have accelerated, and the new database shows a recent increase in projects cost-shared by the electric power industry.

The database provides information about the efforts of various industries, public groups, and governments to develop and deploy CCS technology, a critical component in global efforts to reduce greenhouse gas emissions.

It lists technologies being developed for capture, testing sites for CO2 storage, and estimations of costs and anticipated dates of project completion, and uses Google Earth to illustrate the location of projects and provide a link to further information on each.

The database will be continually updated as information about new or existing projects is released. NETL welcomes project updates and comments that will improve the database. Contact information to provide updates or comments is available in the step-by-step instructions available from the database webpage.

US and China cooperate on clean energy

www.energy.gov

President Barack Obama and President Hu Jintao have announced a package of measures to strengthen cooperation between the United States and China on clean energy including CCS.

The two Presidents announced the establishment of the U.S.-China Clean Energy Research Center. The Center will facilitate joint research and development of clean energy technologies by teams of scientists and engineers from the United States and China, as well as serve as a clearinghouse to help researchers in each country.

The Center will be supported by public and private funding of at least $150 million over five years, split evenly between the two countries. Initial research priorities will be building energy efficiency, clean coal including carbon capture and storage, and clean vehicles.

21st Century Coal

The two Presidents pledged to promote cooperation on cleaner uses of coal, including large-scale carbon capture and storage (CCS) demonstration projects.

Through the new U.S.-China Clean Energy Research Center, the two countries are launching a program of technical cooperation to bring teams of U.S. and Chinese scientists and engineers together in developing clean coal and CCS technologies.

The two governments are also actively engaging industry, academia, and civil society in advancing clean coal and CCS solutions. The Presidents announced: (i) a grant from the U.S. Trade and Development Agency to the China Power Engineering and Consulting Group Corporation to support a feasibility study for an integrated gasification combined cycle (IGCC) power plant in China using American technology, (ii) an agreement by Missouri-based Peabody Energy to participate in GreenGen, a project of several major Chinese energy companies to develop a near-zero emissions coal-fired power plant, (iii) an agreement between GE and Shenhua Corporation to collaborate on the development and deployment of IGCC and other clean coal technologies; and (iv) an agreement between AES and Songzao Coal and Electric Company to use methane captured from a coal mine in Chongqing, China, to generate electricity and reduce greenhouse gas emissions.

U.S.-China Energy Cooperation Program.

The two Presidents announced the establishment of the U.S.-China Energy Cooperation Program. The program will leverage private sector resources for project development work in China across a broad array of clean energy projects, to the benefit of both nations. More than 22 companies are founding members of the program.

The ECP will include collaborative projects on renewable energy, smart grid, clean transportation, green building, clean coal, combined heat and power, and energy efficiency.

Siemens to supply IGCC with CCS to Tenaska

www.siemens.com/energy

Siemens Energy has been chosen by Tenaska, based in Omaha, Nebraska to provide the coal gasification technology for the Taylorville Energy Center (TEC).

With a gross capacity of 730 megawatt (MW) the advanced clean coal generating plant will be one of the first commercial-scale coal gasification plants with carbon capture and storage (CCS) capability in the U.S.A.

Tenaska is the managing partner of the $3.5 billion facility which will convert Illinois coal into substitute natural gas (SNG). The gas will be used for electricity generation or fed into the interstate natural gas pipeline system.

TEC's integrated gasification combined-cycle (IGCC) technology will capture and provide storage for at least fifty percent of the carbon dioxide (CO2). The TEC is scheduled to be completed in 2014.

For the TEC, being developed near Taylorville, Illinois, Siemens will provide equipment contracts and licensing agreements for four 500-megawatt-class gasifiers. These gasifiers have a daily processing capacity of as much as 2,000 metric tons of coal or petcoke.

In the gasification process, a wide range of coals or other carbon-containing feedstocks, such as biomass or refinery residues, can be converted to syngas and subsequently cleaned to remove environmental pollutants such as sulfur, mercury and carbon dioxide.

The syngas can then be used for environmentally compatible power generation in IGCC plants or as raw material for the chemical industry through the production of chemical feedstocks or synthetic fuels.

Alberta finances Swan Hills project

www.energy.alberta.ca

The Alberta Government has signed a Letter of Intent with Swan Hills Synfuels for an in-situ coal gasification project with CCS.

The project will use an in-situ coal gasification (ISCG) process to access coal seams that have traditionally been considered too deep to mine. The coal seams, located about 1,400 metres beneath the earth's surface, will be accessed through wells that are similar to conventional oil and gas wells. The ISCG wells will be used to convert the coal underground in its original seam into syngas.

The syngas will be piped to the Whitecourt area to fuel new high-efficiency combined cycle power generation for Alberta's electricity market. It will provide about 300 MW of generation capacity.

The CO2 created during the gasification process will be captured and used for enhanced oil recovery (EOR) in the Swan Hills area.

The province will invest $285 million in the Swan Hills project, from its $2 billion Carbon Capture and Storage Fund. Construction is expected to begin in 2011 with carbon capture scheduled to start by 2015.

GE and Shenhua Group cooperate on clean power

www.ge.com/energy

GE and Shenhua Group Corporation have announced that they have agreed to a framework for an industrial coal gasification joint venture.

The memorandum of understanding, which was signed as part of the U.S.-China clean energy cooperation signing ceremony in Beijing, would result in a joint venture company, in which GE and Shenhua would seek to improve cost and performance of commercial scale gasification and integrated gasification combined cycle (IGCC) solutions.

This includes industrial coal gasification applications in China as well as jointly pursuing the deployment of commercial scale IGCC plants with carbon capture.

The parties anticipate that the transac-

tion would be completed in the first half of 2010, subject to the negotiation of definitive agreements and obtaining all required approvals.

GE's gasification technology is one of the most widely applied technologies of its kind in China, with more than 40 licensed facilities.

Total inaugurates Lacq project

www.total.com

Total has inaugurated Europe's first end-to-end carbon capture, transportation and storage demonstration facility, in Lacq, southwestern France.

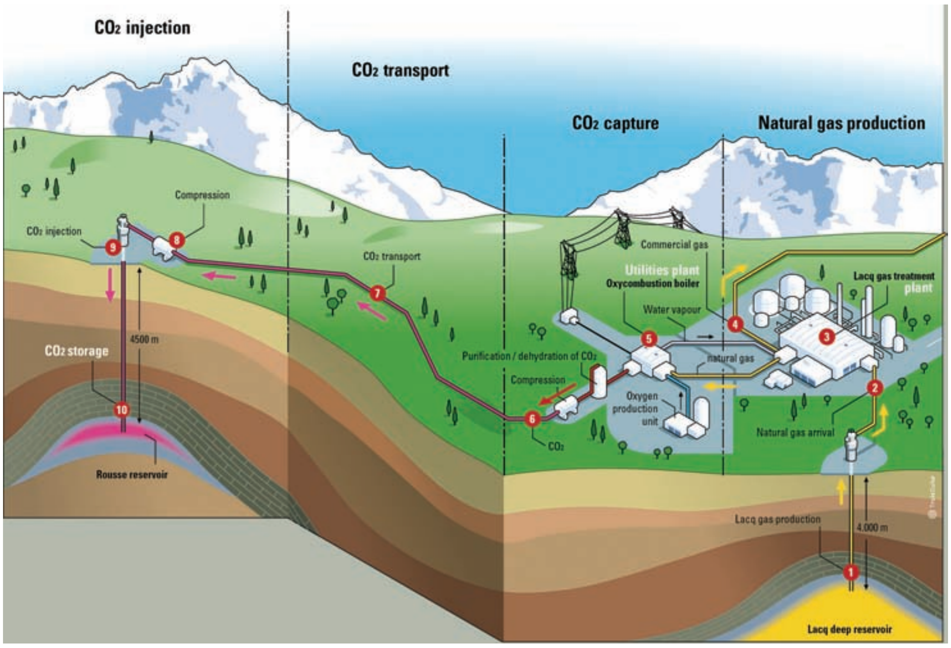
The ceremony was attended by Valérie Létard, France's Secretary of State for Green Technology and Climate Negotiations.

The €60-million project uses an oxy-combustion carbon capture technology developed by Air Liquide. Pure oxygen is substituted for air in an industrial boiler to produce smaller amounts of flue gas that is 90% carbon.

The carbon is piped 27 kilometers from the Lacq plant to the Rousse geological storage site, where it is injected into a depleted natural gas reservoir located 4,500 meters belowground.

Over the next two years, around 120,000 metric tons of carbon dioxide will be captured and stored, equivalent to the amount that would be emitted by 40,000 cars over the same period.

The launch of the demonstration project was preceded by wide-ranging consultation of local stakeholders. Monitoring will continue for three years after the two-year carbon injection period.



Total's Lacq pilot in Southwest France

Fortum, TVO and Maersk join for Finnish project

www.fortum.com

Finnish utilities Fortum and Teollisuuden Voima (TVO) have entered into co-operation with Maersk Oil and Maersk Tankers for a CO2 capture, shipping and storage project.

The partners wish to combine carbon capture at the Meri-Pori power plant with CO2 transportation by Maersk Tankers' vessels and geological storage.

Maersk Oil will investigate the possibility of providing final CO2 storage in the depleting oil and gas fields of the Danish North Sea, as well as the potential use of CO2 for Enhanced Oil Recovery (EOR).

The aim is to capture, transport and store in excess of 1.2 million tonnes CO2 per year. Fortum and TVO have previously selected Siemens Energy as the CO2-capture technology partner for the project.

Subject to successful project development, the project will seek qualification for funding under the European Union's CCS Demonstration Programme. The selection for this funding is expected to take place in 2011 and the final investment decision in 2011-2012. The project aims to be in operation by 2015.

The coal-fired power plant is located at Pori on the west coast of Finland and has an installed capacity of 565 MW. The CCS demonstration is planned to process approximately 50 percent of the plant's flue gas and to capture 90 percent of the CO2 it contains with Siemens' proprietary post-combustion capture technology.

Meri-Pori's CCS demonstration is among the largest post-combustion capture projects yet announced in Europe, the first to combine shipping, cross border transportation between two EU countries and enhanced oil recovery options.

Maersk Tankers already has the blueprints to build tanker vessels for the transport of CO2 from emission sources to storage sites. The vessels will be semi-pressurised and semi-refrigerated, keeping the CO2 liquid. Maersk Tankers has designed the vessels, based on years of experience with transportation of liquefied petrochemicals and natural gas, and in accordance with global standards.

Sasol to participate in Norway Mongstad project

www.sasol.com

Sasol and Gassnova SF have signed an MoU on participation in Norway's CO2 Technology Centre in Mongstad.

The MoU will enable Sasol to explore the possibility of becoming a participant in the European CO2 Technology Centre Mongstad (TCM) currently under construction in Norway.

The signing of the MoU by Sasol CE, Pat Davies and Bjørn-Erik Haugan, CEO of Gassnova SF and chairman of TCM DA, took place in the presence of South African President, Jacob Zuma and visiting Norwegian monarchs, King Harald V and Queen Sonja, during their state visit to South Africa.

TCM is an international technology co-operation, established to test, verify and demonstrate technology suitable for deployment at large scale CO2- capture facilities. The current TCM partners are Gassnova SF, A/S Norske Shell and Statoil ASA, with Gassnova SF representing the Norwegian State in the project.

The technology centre is currently under construction at Mongstad on the west coast of Norway and will be in operation by the end of 2011. The test facilities are planned to capture 100,000 tons of CO2 per annum.

EU demonstrates CCS projects at DNV

www.dnv.com

The European Commission has held the preparatory meeting for its new knowledge-sharing network of CCS demonstration projects.

The meeting gathered delegates from 22 projects in 13 European countries.

The network, which is set up to speed up the process towards full-scale industry implementation of CCS technology, is coordinated by DNV.

European CCS demonstration projects fulfilling a set of qualification criteria participated in the launch at Høvik on Decem-

ber 2 and 3. The purpose of the network is to facilitate a process to shorten the time from policy making to industry implementation of CCS.

After the initial introductory phases the network will provide the first-movers within the field with a means of coordination, exchange of information and experience. There will also be a focus on identifying best practices, and thereby ensuring that the best technologies available in Europe are utilized to their full potential.

Furthermore the network will work closely with other international and national initiatives. Alltogether the network will enable the participants to maximize the impact of research and development and optimize costs through shared actions.

DNV's role is to assist the European Commission in establishing and facilitating the gathering and sharing of information. DNV will organise knowledge sharing events and has recently, together with the European Commission, initiated a web-based platform. All are designed to help focus the policies and actions that are needed in order to establish a long-term value chain for CO2.

DNV is also responsible for providing specialized services relating to information and communication functions within the network, in addition to knowledge management and CCS technology.

DNV has taken an active role in initiating industry efforts aimed at solving common technology challenges for years. Early next year DNV will launch three guidelines on CCS. DNV is also one of the founding members of the Global Carbon Capture and Storage Institute.

First CCS professor at Durham University

www.durham.ac.uk

John Gluyas has been appointed as Durham University's Professor in Geoenergy and Carbon Capture & Storage.

Professor Gluyas will take up his new role within the Department of Earth Sciences after previously holding the position of Head of New Business / Head of Geoscience at Fairfield Energy.

He will be researching aspects of geoenergy (petroleum, geothermal, clean coal) and carbon capture and storage within the newly created Durham Energy Institute. The aim of the new Durham Energy Institute is to find ways to create affordable, reliable, clean energy for heat, power and transport.

The new post is sponsored by Ikon Science and DONG Energy (UK) Ltd. As part of its sponsorship, Ikon Science will develop and commercialise new technologies for monitoring and modelling the injection and storage of CO2 into the earth.

Basin Electric Power Cooperative plans to construct the Carbon Dioxide Capture Plant at its Antelope Valley Station located near Beulah, North Dakota

Doosan Babcock selected by Basin Electric Power for Dakota project

www.doosanbabcock.com

www.htcenergy.com

Doosan Babcock has been selected to undertake a major carbon capture project with US utility Basin Electric Power Co-operative.

The project will be led by Doosan Babcock in partnership with Canadian carbon capture technology firm, HTC Purenergy.

The eventual aim of the project is to use the captured CO2 for enhanced oil recovery close to the power plant with the CO2 subsequently stored underground.

The initial engineering phase will commence in January and will provide Basin Electric with a comprehensive assessment to enable them to make a decision on the final project notice to proceed for the CO2 capture plant solution.

Basin Electric Power Cooperative plans to construct the Carbon Dioxide Capture Plant at its Antelope Valley Station located near Beulah, North Dakota.

ZeroGen short-listed for CCS Flagships funding

www.zerogen.com.au

Queensland's ZeroGen project has been short-listed by the Australian Federal Government for funding under its $2 billion Carbon Capture and Storage Flagships Program.

The company is proposing to build a commercial scale baseload Integrated Gasification Combined Cycle (IGCC) with Carbon Capture and Storage (CCS) low emission coal power plant in Central Queensland by late 2015.

ZeroGen Chief Executive Officer, Dr Tony Tarr said ZeroGen was clearly now well placed to become one of the first commercial-scale IGCC with CCS projects in the world following today's announcement by the Minister for Resources and Energy, Martin Ferguson.

The project is currently funded by its partners the State Government, Australian Coal Association Low Emissions Technologies Ltd (ACALET), and Japan's Mitsubishi Corporation and Mitsubishi Heavy Industries.

The Carbon Sequestration Leadership Forum, of which Australia and Japan are members, recently recognised the project as one of the most important Carbon Capture and Storage projects in the world and it is one of 10 new projects now added to the existing CSLF portfolio of Research and Developments projects.

ZeroGen's CO2 drilling exploration program is continuing in Central Queensland and is the most advanced of its kind in the world.

An extensive prefeasibility study, to be completed mid 2010, is examining the potential for the power plant to be built in the Central Highlands region, close to coal supply, existing infrastructure and a secure storage site for its CO2 emissions.

An Environmental Impact Study will also be completed as part of the feasibility process and on current timelines all studies are expected to be completed by September 2011. An extensive community consultation program will be carried out throughout these studies.

Environmental foundation ZERO launches CCS website

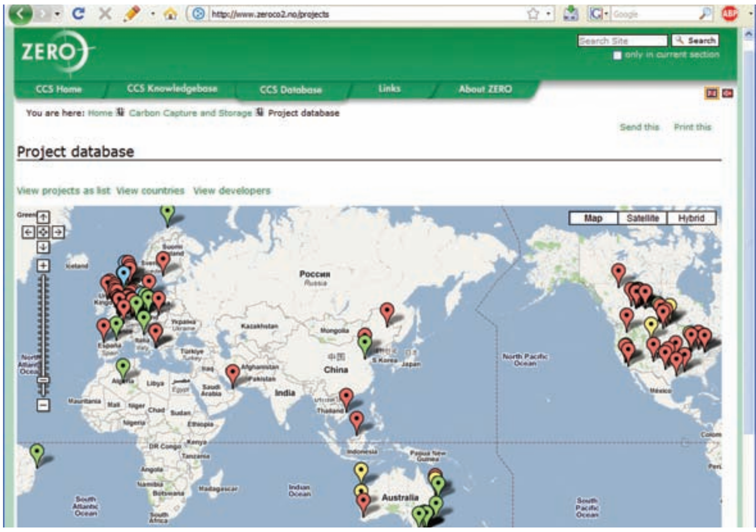
www.zeroco2.no

The website seeks to provide comprehensive and transparent information on CCS.

On ZEROCO2 you will find answers to questions often raised in relation to carbon capture and storage. There is a map and extended facts on the world's various CCS projects, and a "wiki-part" with all the information you may need about the entire CCS chain.

"As far as we know, this is the only website worldwide where you can find expanded information related to all CCS projects. You can find out where the world's countries stand in the development and implementation of carbon capture and storage of CO2," says Audun Rødningsby, Advisor CCS, ZERO.

The site provides an extensive amount of factual information from an NGO perspective, at a high level, including detailed information about the various technologies and items in the CO2 chain, and a comprehensive worldwide project database.



The ZEROCO2 website features a worldwide project map as well as other comprehensive information about CCS

OE best practices manual for public outreach and education for CCS

The U.S. Department of Energy's Regional Carbon Sequestration Partnerships program has released a new manual to recommend best practices for public outreach and education for carbon dioxide storage projects.

The recommendations are based on lessons learned by the Department's seven Regional Carbon Sequestration Partnerships during the first six years of the partnerships program.

The new publication, titled Best Practices for Public Outreach and Education for Carbon Storage Projects, is intended to assist project developers in understanding and applying best outreach practices for siting and operating CO2 storage projects. The manual provides practical, experience-based guidance on designing and conducting effective public outreach activities.

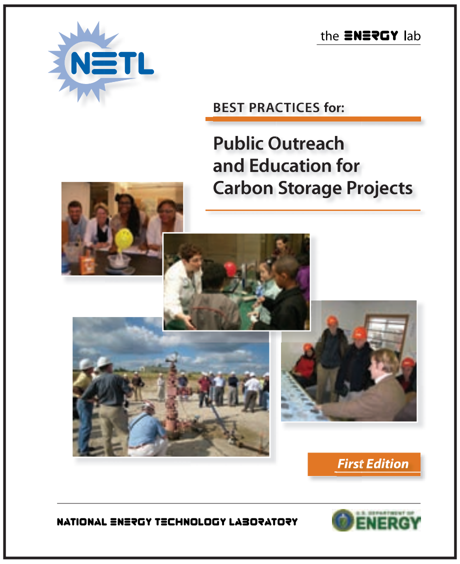
The Office of Fossil Energy launched the Regional Carbon Sequestration Partnerships program in 2003 to develop and validate carbon capture and storage technologies as part of a national strategy to reduce greenhouse gas emissions and mitigate global climate change.

Seven regional partnerships form the centerpiece of national efforts to develop the infrastructure and knowledge base needed to place carbon capture and storage technologies on the path to commercialization. Each of the partnerships works with local organizations and citizens who contribute expertise, experience, and perspectives that represent the concerns and desires of a given region.

The partnerships recognize that carbon storage projects take place in a social setting. The best practices highlighted in the new manual take into account the social context within which projects are deployed. They add a valuable perspective by addressing the critical social implications of implementing CO2 storage projects across a variety of U.S. geologic and cultural settings.

To date, nearly two dozen CO2 storage field verification tests nationwide are in progress or have been completed by the partnerships. These early projects have been highly visible, and their success will likely impact future carbon storage projects, such as the large-scale CO2 storage projects the partnerships are now initiating in their respective regions.

The primary lesson learned from the partnerships' experience is that public outreach should be an integrated component of project management. Conducting effective public outreach will not necessarily ensure project success, but underestimating its importance can contribute to significant delays, increased costs, and lack of community acceptance. Outreach is not simply an add-on activity— it is integral to implementation of the project.



In addition to the finding that public outreach should be an integral component of project management, the manual outlines an additional nine best practices. In combination, these ten practices represent a framework for designing an outreach program that is tailored to the specific characteristics of a planned project, the project developers, and the community in which the project is planned.

Capture news

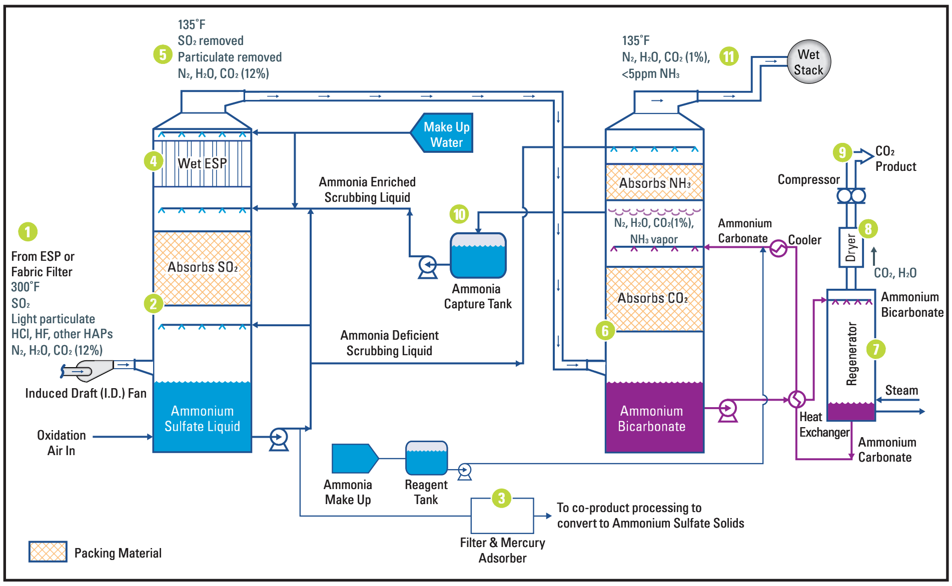
Powerspan announces CO2 capture pilot test results

www.powerspan.com

Powerspan has released test results from a one-megawatt pilot unit demonstrating its post-combustion ECO2 carbon capture technology for coal-fired power plants.

The 1-MW pilot test unit is located at FirstEnergy Corp.'s R.E. Burger Plant near Shadyside, Ohio. The test results show that the pilot unit is meeting its performance goals.

In a real world operating environment, the pilot averaged greater than 90 percent CO2 capture from a slipstream of flue gas from the coal-fired power plant. The pilot performance data provided all of the information needed to move to commercial scale demonstration systems, said the company. Commercial cost estimates based on pilot performance data are less than $50 per ton for CO2 capture and compression.



Powerspan's ECO2 process control

During extended runs, the pilot unit averaged greater than 90 percent CO2 capture at design inlet CO2 conditions with regeneration energy of less than 1,200 Btu/lb after heat integration. The product CO2 was purified to meet industrial pipeline specifications using equipment that is part of the pilot installation. The pilot unit has demonstrated that it can adapt to the normal changes of an operating power plant, which is a necessary step in moving toward commercial scale systems.

In early 2010, Powerspan plans to publish an independent review of pilot test results along with an independent assessment of commercial cost implications. This review will be conducted by a leading global provider of engineering services to the energy, resource, and chemical process industries.

ScottishPower reports CO2 capture efficiency 'breakthrough'

www.scottishpower.com

ScottishPower says it has reduced the energy consumption for CO2 capture at its prototype carbon capture unit at Longannet Power Station by around a third.

Technicians have been monitoring the effectiveness of the amine plant that captures the CO2 under a range of operating conditions. The focus for the tests at Longannet has been to reduce the energy requirement to a minimum via a combination of process improvements and low energy solvents.

The improved process has been successfully verified in the pilot plant, with the energy required being reduced by approximately a third from a reference plant.

The prototype carbon capture unit is the first of its kind to be demonstrated on a working coal-fired power station in the UK, and has been successfully operating for over 2000 hours. The unit is monitored 24 hours a day and has been capturing around 90% of the carbon content from 1000 cubic metres an hour of exhaust gas at Longannet.

It is an integrated part of the SOLVit research and development programme. The main focus of the programme is to develop more efficient solvents that require less energy and are more robust in coal operation.

All members in the ScottishPower Consortium have gained crucial experience and knowledge from the tests at Longannet. The test unit has also hosted visits from power firms and other interested parties from China, the United States, Australia and a number of countries across Europe.

CO2 Solution announces enzymatic carbon capture results

www.co2solution.com

CO2 Solution says it has achieved 'significant' results when applying its patented genetically engineered '5X' carbonic anhydrase enzyme to CO2 capture with certain carbonate and amine absorbent solutions.

In tests with low-energy absorbent solutions, the use of the enzyme increased the CO2 reaction rate more than 50 times, the company says.

The testing was carried out in collaboration with CO2 Solution's process partner, Procede Group B.V., a leading chemical engineering firm. The Co-Founder of Procede, Dr. Geert Versteeg is also member of CO2 Solution's Scientific Advisory Board. CO2 Solution will use these results to develop an optimized process for field testing, which it is planning to begin in Canada in 2010.

CO2 Solution has also filed three new patent applications in the field of enzymatic carbon capture which it believes will have significant value by further expanding the range of application of its enzymatic technology in packed columns and other scrubbing systems.

Amongst the patent applications, is a new enzyme delivery method which the Company believes will provide for further improvements in using carbonic anhydrase for efficient CO2 capture.

DNV and PSE joint project for maritime CCS

www.psenterprise.com

Det Norske Veritas AS and Process Systems Enterprise Ltd (PSE) have announced a collaborative R&D project aimed at developing blueprint designs for on-ship carbon capture and storage (CCS) technology to reduce maritime CO2 emissions.

A recent International Maritime Organisation (IMO) study estimates maritime CO2 emissions at over 1000m tonnes per year, about 3% of total anthropogenic CO2 emissions. With these expected to increase threefold by 2050 the IMO is likely to introduce regulations to reduce emissions.

Because ship emissions are concentrated – unlike other forms of transport – there

is potential to capture CO2 at source. However, this requires innovative technology. The Maritime CCS project aims to develop a blueprint design for an on-board process for chemical capture and temporary storage of CO2 for ships in transit until discharge into transmission and storage infrastructures at the next suitable port.

The project, jointly financed by the two partners plus the UK's Technology Strategy Board and the Norwegian Research Council under the Eurostars initiative (www.eurostars-eureka.eu), will take into account the unique challenges posed by the maritime environment, including constant ship movement, limited space and access to utilities, stringent safety requirements and the need for energy efficiency.

Project leader PSE is a leader in model-based innovation (MBI), which applies high-fidelity mathematical models to accelerate innovation, manage development risk and optimise process design and operation. Its gPROMS modelling technology is widely used in the oil & gas, chemicals, power generation, clean energy and other process sectors, and underpins much current European R&D in CCS applications.

DNV is a world-leading classification society that assists its customers within the maritime industry to manage their risks in all phases of a ship's life, through ship classification, statutory certification, fuel testing and a range of technical, business risk and competency-related services.

The economics of transportation of CO2 in common carrier network pipeline systems

Large-scale CCS will require large-scale infrastructure to move CO2 from capture facility to storage formation. Significant resources will have to be dedicated in order to construct and operate a pipeline system. Many of the design considerations and technologies in large-scale systems are already used by the oil and gas sector in existing hydrocarbon pipeline applications. Because of this experience, the oil and gas industry can play a crucial role in determining a way forward for transporting CO2 to make possible large-scale, commercial deployment of carbon capture and storage.

By Mark Bohm, Climate Change Engineering Specialist with Suncor Energy, a CO2 Capture Project member company

Establishing a widespread CO2 transportation infrastructure requires a strategic approach that takes into account the magnitude of potential deployment scenarios for CCS with hundreds of megatonnes (Mt) of CO2 transported every year through pipeline systems. Transporting CO¬2 by pipeline is not a new technology; in the US almost 4,000 miles of CO2 pipeline for enhanced oil recovery (EOR) are in operation. However, the infrastructure for mass CCS could be on the scale of the current gas transmission infrastructure for Europe or North America, and will require significant investment to construct and operate.

The CO2 Capture Project (a partnership of seven oil and gas majors to advance CCS) has been looking at the issues surrounding the economics of transportation of CO2 in common carrier network pipeline systems. The CCP commissioned a study to examine different approaches to infrastructure development. In the study two approaches have been evaluated.

The first would see the development of a point-to-point system, the second the development of common carrier pipeline networks, including backbone pipeline systems. This study has helped our understanding of the challenges involved; shedding light on what would be the best scenario and how in practical terms CO2 infrastructure might evolve. The results of this study were presented in a paper - Assessing issues of financing a CO2 transportation pipeline infrastructure commissioned by the CCP, and completed by Environmental Resources Management (ERM).

Results of the Study

The study confirmed that an integrated backbone pipeline network is likely to be the most efficient long-term option. It offers the lowest average cost on a per tonne basis for operators over the life of the projects if sufficient capacity utilization is achieved relatively early in the life of the pipeline.

Crucially, integrated pipelines reduce the barriers to entry and are more likely to lead to the faster development and deployment of carbon capture and storage. Particularly in situations where government money is being used to finance CO2 transportation it makes sense to pursue an integrated approach that provides equitable, open access to other large final emitters. This will reduce the barriers to entry and will encourage faster adoption of CCS. However, point-to-point pipelines offer lower costs for the first movers and do not have the same capacity utilization risk.

It is clear that without government incentives for the development of optimized networks, project developers are likely to build point-to-point pipelines. Other forms of financial support may be needed which overcome commercial barriers and ensure optimized development of CO2 pipeline networks

So what is the way forward? Guaranteed capacity utilization is essential for integrated backbone pipeline networks to become economically viable. Public policy is needed that provides some guarantees as to capacity utilization. Government incentives or loan guarantees are also needed to support a backbone infrastructure and encourage the development of optimized networks. Government support in the first years, when capacity is ramping up, will be essential for eventual commercial viability.

CCP is continuing its research into understanding the financial and policy mechanisms that can be applied to enable the large scale deployment of CCS at lowest cost. Additional work includes a detailed assessment of financing and incentives mechanisms.

More information

For the complete paper, and to be kept up-to-date on all the latest developments please visit:
www.co2captureproject.org

Do wells represent a risk for CO2 Storage projects?

How can we demonstrate the safety of the storage, and particularly, the performance of all existing wells (exploration wells, open wells, P&A'd wells) in the field to confine the CO2 inside the reservoir.

By Dr. Yvi LE GUEN, consultant engineer in risk management and well integrity, OXAND, France

Well Integrity Issues of CO2 Geological Storage

The Carbon Capture and Storage technology available today offers a promising solution to mitigate CO2 emission into the atmosphere. However, while the conditions necessary for the commercial deployment of this technology seem always closer, key issues remain to be addressed before launching large-scale operations: further investigations into the associated risks are required to ensure cost, safety and environmental issues.

A viable CO2 storage site must meet capacity, injectivity and confinement requirements. This last requirement is particularly important from safety and environmental aspects. It is a key challenge to address any possible health, safety or environmental concerns related to this new technology to allow full-scale projects deployment as recommended by IEA roadmap in 2009 (www.iea.org/roadmaps/ccs_power.asp), and supported by the recently founded Global CCS Institute (GCCSI, www.globalccsinstitute.com).

Focusing on the subsurface, CO2 storage will be designed for no leakage over the project's lifecycle (from operation to post abandonment). Although faults and fractures have been generally identified as potential CO2 leakage pathways, it is believed that these pose small risks if storage sites are properly selected and operated. On the other hand, wells have been identified as posing a greater risk for leakage (IPCC, 2005), particularly in densely-drilled onshore sedimentary basins like those in North America (such as Texas or Canada) where hundreds of thousand (100,000's) of wells have already been drilled (Figure 1).

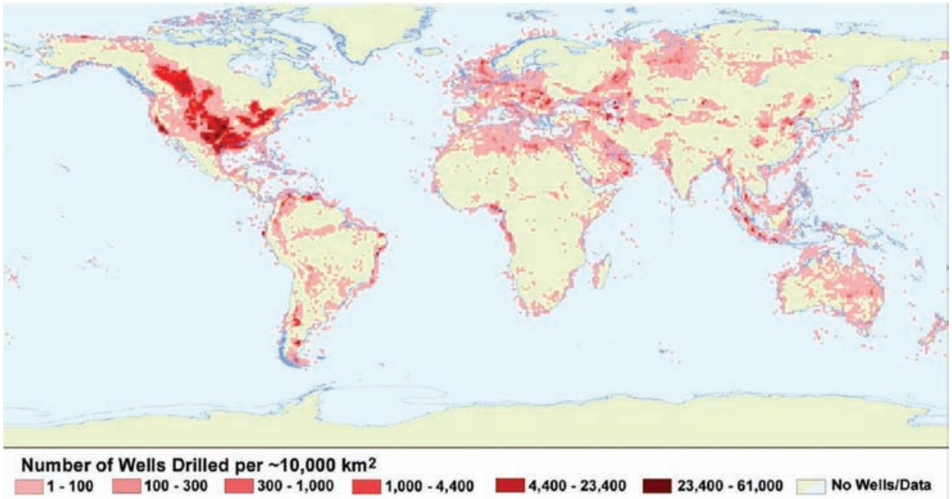


Figure 1: World Oil and Gas Well Distribution and Density (IPCC, 2005)

Each well is a potential path for the CO2 from the reservoir to various targets (fresh water aquifer, surface …) but they have to maintain sealing from some tens of years (operational phase) to some hundreds of years (post-abandonment) despite initial wells' quality, and alteration processes (physical, chemcial, mechanical) that may impact wells' performance over time (Figure 2).

The implementation of any CO2 storage projects will preliminarily require an assessment of the risks regarding wells' integrity, answering some key questions:

- Is CO2 likely to migrate through the wells over time? Through which wells?
- What are the possible migration pathways?
- Which wells' components might favour CO2 migration? (Poor cement barrier's quality, casing failure, inappropriate abandonment strategies, etc)
- How degradation processes will impact wells' integrity over time? (Cement leaching by acid gas degradation, corrosion of casings and steel materials, mechanical impact of geology, development of micro-annulus at interfaces, etc.)
- What should be done to treat critical risks associated to well integrity? (Inspections and characterization, workovers, monitoring, modification of the injection strategy…)
- How to demonstrate CO2 long term confinement and safety to authorities?

Performance and safety demonstration of a high number of wells

In order to address this issue, a risk-based approach (Performance and the Risk, P&R™) was developed and applied to support operators in managing the integrity of a high number of wells of a potential site. It was designed to proactively anticipate and/or reduce the risks regarding wells on a specific site. Main specificities of the approach are:

- A well-structured process combining expert opinion, data interpretation, checklist, quantitative modeling and recommendations
- The process goes in different steps from a "macro" view of the wells of the site, at an early stage of a CCS project (feasibility phase, site selection for example) to a "micro" analysis of the wells and their components (operational phase) to define specific actions to treat critical risks if any;

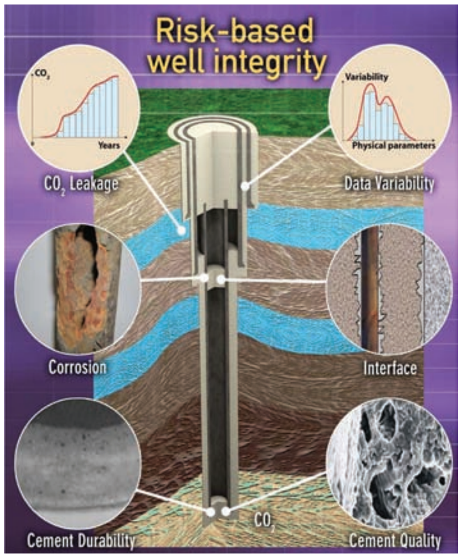


Figure 2: Illustration of Well Integrity Issues

• At the end of each step, the operator has an overview of the wells integrity (with an increasing level of detail while going through each step of the approach) with a set of recommendations to support decision-making regarding well integrity issues in coherence of the project development: go/no go for a site, going more in detail, which inputs are required…

• Both the impact (severity) and the uncertainties (probability) of leakages are considered for a more comprehensive view of the wells system;

The final objectives of the approach are to ensure that wells' performance to confine the CO2 is high over its lifecycle, associated risk levels are acceptable, and to support the safety demonstration regarding the authorities and the public if required.

The major steps of the Performance and Risk approach are (a workflow is proposed in figure 3):

1. First data collection and first wells screening;
2. Second data collection and semi-quantitative assessment of wells;
3. Quantitative risk assessment of risky wells;
4. Final ranking of all the wells regarding well integrity;
5. Recommendations for risk treatment (if required);

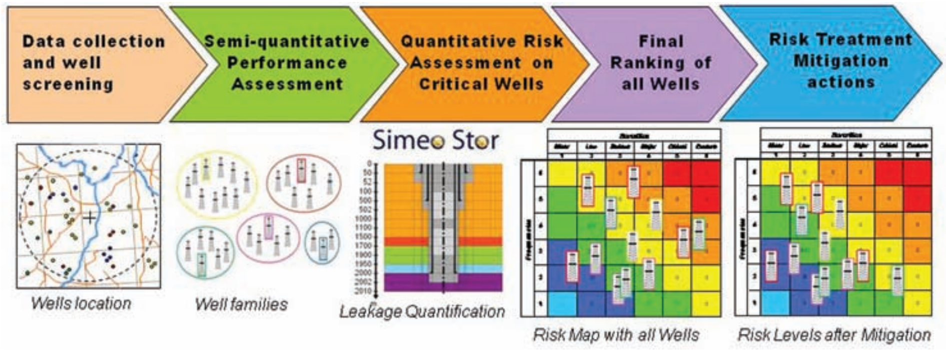


Figure 3: Workflow to Manage Issues Resulting from Multiple Wells

1. First data collection and first wells screening

The objective of this 1st step is to have a clear overview of all the wells of a potential CO2 field, and a first assessment of their exposure regarding CO2 injection.

A detailed data collection is not required for this 1st step as "macro criteria" (based on wells location, major geological formations and target reservoirs, well status, well exposure to injected CO2 and/or others geological fluids, etc) are considered for this first screening of the wells on the site(s). It uses the experts' opinion through a structured process and checklists.

The output is a clear overview of all the wells of the potential field(s) for site selection, and a first ranking of the wells (from macro perspective) regarding their potential exposure to CO2 and the potential impact of CO2 leakages on main objectives.

2. Second data collection and semi-quantitative assessment of wells

The objectives of this 2nd step are to initiate a semi-quantitative well integrity assessment thanks to key indicators based on occurrence of a CO2 leakage and possible impact on different targets. These key indicators are focused on barriers presence, uncertainties, possible failure mode, impact…. A multi-criteria analysis enables to provide a well ranking regarding their integrity and possible leakage impact and the identification of the "risky" wells to be analyzed in priority;

The output is an estimation of key indicators for each well of the site and a detailed ranking of the wells. The ranking allows to group wells depending on their potential severity and probability, wells with greater severity (low confinement performance) and greater probability should be considered more in details in the next step.

3. Quantitative risk assessment of risky wells

The objective is to assess quantitatively the risk levels of the more risky wells to identify risk sources, CO2 migration pathways within the wells and later define detailed mitigation actions. This implies addressing in detail, for the group of risky wells only, the key questions detailed previously (such as leakage paths, weak wells' components, targets affected by CO2) using a quantitative methodology (Le Guen et al., 2008; Meyer et al., 2008).

Depending on the well's number and on their similarities, a strategy using 'well families' could be considered. A 'well family' gathers wells with similar properties (regarding geometrical, mechanical, semi-quantitative risk levels) which can be depicted by a 'representative well'.

The Performance and Risk assessment of the individual wells or of the "representative" wells of each family includes the definition models for each well, construction of scenarios, CO2 migration simulations, risk quantification, and finally the identification of components that favours CO2 confinement (Figure 4).

The output is a quantification of wells' confinement performance towards identified targets (aquifers, fresh water, and atmosphere) and associated probability to quantify risk levels.

4. Final ranking of all the wells regarding well integrity

Based on the results of the previous steps, the objective is to propose a risk-based ranking of all the wells the selected field. This requires gathering all the wells on a unique map using criteria relevant to the performance of the well (i.e. confinement of CO2) and the associated uncertainties.

This map gives an overview of the "risk" levels associated to all the wells of the selected storage site, and enables to compare the wells (Figure 5a). Based on operator standards and usual practice in terms of risk management, wells with critical risk levels can be identified.

5. Recommendations for risk mitigation (if required)

If some wells have a risk level above operator level of acceptance, the objective of this final step is to define action plans and recommendations that will finally demonstrate risky wells performance in confining the CO2 in the selected reservoir. Recommendations are based on the results of step 3 and 4, in consistency with risk sources, to decrease either the probability and/or the potential impacts of CO2 leakages (Figure 5b).

They are prioritized for the different wells in time and space depending on risk levels. Actions could be:

• gain additional specific data for some wells;

• improve the well design (well intervention, workovers …);

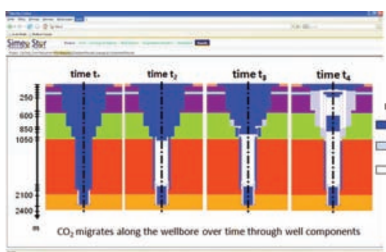


Figure 4: Example of Well Modelling Results: CO2 Migration along a Wellbore

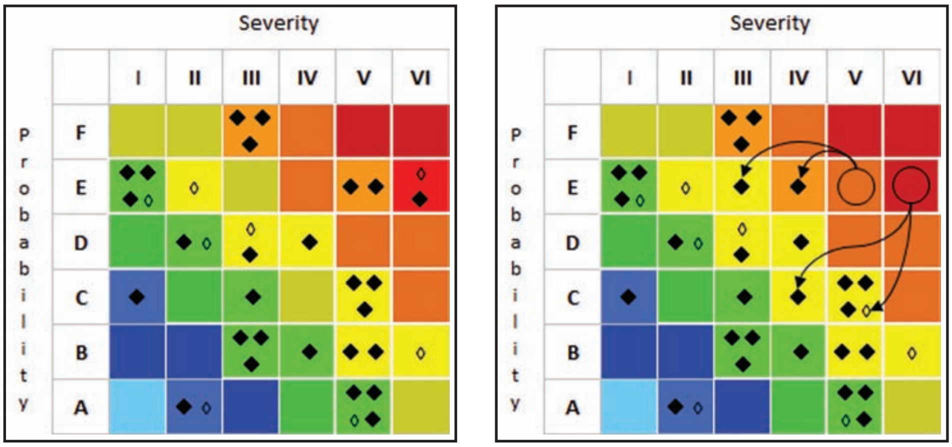


Figure 5: a) Map of Severity and Probability Levels for each Well of a Field (each Diamond is a Well); b) estimation of the impact of mitigation actions on risk levels of some wells

• improve knowledge on processes (such as ageing, failure mode) or numerical modelling (CO2 reactive flow transport) (decrease of uncertainties);

• Define and implement monitoring tools to follow the evolution of CO2 along wells over time.

Conclusions

The use of a risk-based solution is an important improvement to best practices thanks to their capability to have a full picture of the system considering a wide range of objectives (such as financial, safety, environment, and public acceptance) and the uncertainties of the system. Moreover risk-based approaches offer a support for decision making to engage relevant programs to manage and demonstrate system performance over its lifecycle, and to communicate on associated decisions.

Issues associated with the presence of a high number of wells on a storage site can be addressed with the proposed risk-based approach. It enables an assessment of the performance of the wells and associated risk levels, and, if necessary, to define action plans to treat unacceptable risks. The results enable one to give the following answers:

• The wells are safe and will efficiently confine the injected CO2 over long term;

• Risk level of each well is below the operator's level of acceptance and under control;

• Actions were defined to ensure the confinement efficiency of the wells with the greater risk levels.

The results of this approach provide a comprehensive foundation for establishing site specific acceptance criteria and prioritizing future works on a specific site regarding wells and their long term performance for a CO2 storage project. The method that has been presented above is patented by Oxand and has been developed and applied to several fields to answer the needs of one of the major actors in CCS.

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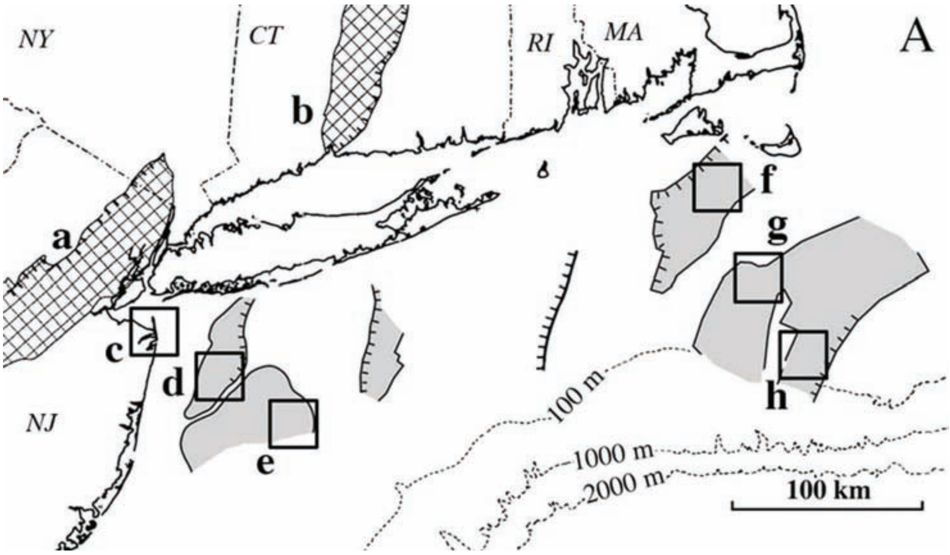
Transport and storage news

US East Coast 'ideal' for carbon storage

www.ldeo.columbia.edu

A report by scientists at Columbia University's Lamont-Doherty Earth Observatory says that igneous basalt has the potential for safe CO2 storage.



Basalt lies under land (hatched areas) and sea (grey areas) along the Northeast coast. Squares indicate possible targets for exploratory drilling. Credit: David S. Goldberg/Lamont-Doherty Earth Observatory.

The study, published in the Proceedings of the National Academy of Sciences outlines formations on land as well as offshore, where the best potential sites may lie.

Underground burial, or sequestration, of globe-warming carbon dioxide is the subject of increasing study across the country. But up till now, research in New York has focused on inland sites where plants might send power-plant emissions into shale, a sedimentary rock that underlies much of the state. Similarly, a proposed coal-fired plant in Linden, N.J. would pump liquefied CO2 offshore into sedimentary sandstone. The idea is controversial because of fears that CO2 might leak. By contrast, the new study targets basalt, an igneous rock, which the scientists say offers significant advantages.

Some basalt on land is already well known and highly visible. The vertical cliffs of the Palisades, along the west bank of the Hudson River near Manhattan, are pure basalt. The formation, created some 200 million years ago, extends into the hills of central New Jersey, and similar masses are found in central Connecticut. Previous research by Lamont scientists and others shows that carbon dioxide injected into basalt undergoes natural chemical reactions that will eventually turn it into a solid mineral resembling limestone. If the process were made to work on a large scale, this would help obviate the danger of leaks.

The study's authors, led by geophysicist David S. Goldberg, used existing research to outline more possible basalt underwater, including four areas of more than 1,000 square kilometers each, off northern New Jersey, Long Island and Massachusetts. A smaller patch appears to lie more or less under the beach of New Jersey's Sandy Hook peninsula, opposite the New York City harbor and not far from the proposed plant in Linden. The undersea formations are inferred from seismic and gravity measurements.

"We would need to drill them to see where we're at," said Goldberg. "But we could potentially do deep burial here. The coast makes sense. That's where people are. That's where power plants are needed. And by going offshore, you can reduce risks." Goldberg and his colleagues previously identified similar formations off the U.S. Northwest.

Goldberg said the undersea formations are potentially most useful, for several reasons. For one, they are deeper—an important factor, since CO2 pressurized into a liquid would have to be placed at least 2,500 feet below the surface for natural pressure to keep it from reverting to a gas and potentially then making its way back to the surface.

The basalts on land are relatively shallow, but those at sea are covered not only by water, but hundreds or thousands of feet of sediment, and they appear to extend far below the seabed. In addition to providing pressure, sediments on top would form impermeable caps, said Goldberg.

The basalts are thought to contain porous, rubbly layers with plenty of interstices where CO2 could fit, simply by displacing seawater. Theoretically, after morphing into a solid, the CO2 would fill those voids. On land, the same reaction might take place, but it is possible that drilling and injection could disturb aquifers or otherwise disturb neighbors on the heavily populated surface.

The scientists estimate that just the small Sandy Hook basin may contain about seven cubic kilometers of the rock, with enough pore space to hold close to a billion tons of CO2—the equivalent of the emissions from four 1-billion-watt coal-fired plants over 40 years. "The basalt itself is very reactive, and in the end, you make limestone," said coauthor Dennis Kent, who is also at Rutgers University. "It's the ultimate repository."

Previous research has identified other areas of basalt sprinkled along the Appalachians. The largest mass of all appears to extend offshore of Georgia and South Carolina, as well as inland. This coast also is populous, and would make a good target, said Goldberg. "The next step would be to get some exploratory surveying and drilling going," he said. The paper suggests a half-dozen spots around New York including the Sandy Hook area, and three off South Carolina, to start with.

The study was also coauthored by geologist and paleontologist Paul Olsen, who has been involved in drilling basalt formations in New Jersey. Preliminary drilling also has been done at Lamont-Doherty Earth Observatory itself, which sits atop the basalt cliffs on the Hudson River's west bank.

DOE tests Indiana formation for CO2 storage potential

fossil.energy.gov

The DOE's Midwest consortium has begun injecting 8,000 tons of CO2 to evaluate the carbon storage potential and test the enhanced oil recovery (EOR) potential of the Clore Formation in Posey County, Indiana.

The injection, which is expected to last 6-8 months, is an integral step in DOE's Regional Carbon Sequestration Partnership program. The Midwest Geological Sequestration Consortium (MGSC) is conducting the field test to assess the most promising strategies for deploying CCS in the Illinois Basin.

In addition to evaluating the Clore Formation as a storage site, the project is assess-

ing the potential for EOR in wells that were previously producing oil, but are now abandoned.

The three-member project team, composed of the Illinois State Geological Survey at the University of Illinois, the Indiana Geological Survey, and Gallagher Drilling Inc., is injecting CO2 into the Mumford Hills oilfield at a depth of about 1,900 feet. The injection well is located among four oil-production wells about 5 miles northeast of New Harmony, Ind.

The full duration of the project will depend on the capability of the reservoir to serve as a storage site, as well as the number of water and CO2 injection cycles that will be needed to reach project goals.

A monitoring, verification, and accounting effort is underway at the site to monitor air and groundwater quality; measure the amount of produced oil, gas, and water; monitor CO2 injection composition, volumes, and rates; and monitor injection pressure and temperature.

EU COCATE CO2 transport project launched

www.ifp.com

The project, led by IFP (France), will look at the problems of rolling out a shared transportation infrastructure capable of connecting geological storage sites with various medium size CO2-emitting industrial facilities.

he project brings together eight other research and industrial partners: the Le Havre Region Development Agency (France), Geogreen (France), Accoat (Denmark), SINTEF Energy Research (Norway), DNV (Norway), TNO (Netherlands), Port of Rotterdam NV (Netherlands) and SANERI (South Africa).

COCATE's objective is to analyze the conditions for transporting the flue gases emitted from several CO2-emitting industrial facilities with a view to pooling the capture process, and for exporting large quantities of captured CO2 to storage areas.

While major industrial facilities can be fitted with their own CO2 capture and transport installations, this does not apply to units that emit less CO2 – from a few tens of thousands to several hundred thousand metric tons – and for which the investment required would be uneconomic. They must pool the CO2 capture and transportation system in order to cut costs and to make CCS an affordable technology.

The Le Havre region and the Port of Rotterdam have been selected as test sites for the research work conducted by the partners involved in the COCATE project. The transportation infrastructure being considered includes two types of network:

- a local low-pressure network to collect the flue gases emitted by various Le Havre-based industrial companies and transport it to various capture centers,

- and a high-pressure network to transport the captured CO2 to the Port of Rotterdam, for storage in depleted North Sea oil and gas fields.

Transport by pipe scenarios (CO2 in supercritical state above 74 bars) or transport by boat scenarios (CO2 transported in refrigerated liquid form (-50°C, 7 bar or -30°C, 15 bar)) will be considered, as will different storage locations.

COCATE will review the technical limitations specific to each of these networks:

- Concerning the upstream low-pressure collection network, the flue gases will be transported as they are to the treatment unit. It will be important to ensure that such transportation is technically and economically feasible (corrosion, instability, dimensioning aspects).

- Concerning the high-pressure network transporting the captured CO2, the R&D work will focus more particularly on the effect of the impurities that are contained in the captured CO2. Depending on the type of capture technology and fuel, various types of impurities can be found in the gas to be transported. The aspects concerning fluid mechanics, corrosion and the inner lining of the pipes will be incorporated.

This work will be supplemented by a risk analysis that will provide data to a safety management tool and by the production of a business model relating to cost optimization and the phase-in of the investment policy.

The three-year project has a total budget of €4.5 million, nearly €3 million of which is contributed by the European Commission.

So far, all the R&D projects in the CO2 transportation field have been exclusively focused on the CO2 emitted by the major emitting industries, in particular power stations.

As the first project dedicated to the issue of pooled CO2 treatment, COCATE should allow medium-sized production sites located in the same geographic area to cut their CO2 emissions in the same way as major industrial facilities.