carbon capture journal

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213 Marsh Wall, London, E14 9FJ, UK
www.carboncapturejournal.com
Tel +44 (0)207 510 4935
Fax +44 (0)207 510 2344

Editor
Keith Forward
editor@carboncapturejournal.com

Publisher
Karl Jeffery
jeffery@thedigitalship.com

Subscriptions
subs@carboncapturejournal.com

Advertising and Sponsorship
Alec Egan
Tel +44 (0)203 051 6548
aegan@onlymedia.co.uk

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Front cover: Cows rest beside a CO2 injection well near Weyburn in southeastern Saskatchewan where more than 16 million tonnes of carbon dioxide have been stored underground

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Alberta - investing in transformative technologies

Alberta, a major North American energy producer, is not only a global leader in funding large-scale carbon capture and storage (CCS) projects, it is also a leader in funding new technologies, with a regulatory program for large industry that uses carbon pricing to support CCS.

Ogho Ikhalo, Alberta Environment

Since July 1, 2007 Alberta has required facilities that emit more than 100,000 tonnes of greenhouse gases annually to reduce their emissions intensity by 12 per cent.

To meet this goal, companies were given four options: improve operations, purchase Alberta-based offset credits, purchase or use Emission Performance Credits, or contribute to the Climate Change and Emissions Management Fund (CCEMF).

This program is unique for two reasons. The commitment was made at a time of strong signals for global action, yet Alberta's program is one of the few carbon pricing systems actually operating in the world today. Secondly, this program uses the price signal to drive technology development at the large facilities.

The companies that choose the CCEMF route are required to pay $15/tonne for emissions that exceed their targets. The goal of the fund is to help finance clean technology that will have a significant, sustainable reduction in greenhouse gas emissions.

In the past three years, more than $187 million (CDN) has been received by the Climate Change and Emissions Management Corporation (CCEMC) to manage. This arms-length organization, which is independent from government, has a multi-stakeholder board. It is comprised of industry leaders from a variety of sectors including chemical producers, oil sands, conventional oil and gas, pipeline, electricity and forestry, academia, municipalities and the public at large.

The CCEMC's board is chaired by Eric Newell, the retired Chair, CEO and President of Syncrude Canada Ltd. Jim Carter, chair of the Alberta Carbon Capture and Storage Development Council and former president of Syncrude, is also on the board.

The Corporation issued its first call for proposals in 2009 and received more than 230 submissions from all over the world. It culled through the applications and asked 30 proponents whose projects best met the criteria to submit more extensive proposals.

Those proposals went through a rigorous process which was overseen by a fairness monitor and reviewed by panel members with varied expertise.

The first set of funding worth $ 71.3 million has been allotted into categories with six energy efficiency projects receiving $5.7 million, five renewable energy projects receiving $37.5 million and five CCS and greening energy projects receiving $28.1 million.

Two major cleaner energy projects received $23.3 million. E-T Energy received $6.86 million for its electro-thermal dynamic stripping process for oil sands development and a consortium of companies, including Nexen Inc. and Suncor Energy, received $16.47 million for its enhanced solvent extraction incorporating electromagnetic heating.

Three CCS projects received $4.8 million:

- HTC Pure Energy Inc. received $315,000 for a CO2 capture FEED study for Devon's Jackfish SAGD facility in northern Alberta;
- GE and partners received $2 million for ceramic membrane-based technology for H2 production with CO2 capture and sequestration and;
- Suncor Energy Inc. and partners received $2.5 million for its OTSG oxy-fuel demonstration project at an oil sands in-situ operation in northern Alberta.

All of companies receiving funding for their projects funded by CCEMF will at a minimum match the dollars being invested.

Full details on the fund and the projects chosen for funding are available at ccemc.ca and details on Alberta's regulations on greenhouse gas emissions are available at www.environment.alberta.ca

Alberta is also providing funding for large-scale CCS projects. In 2008 the province allocated $2 billion to kick-start four steel-in-the-ground projects. The selected project proponents have all signed Letters of Intent with the province and are working toward signing Grant Agreements.

The projects being pursued are: Enhance Energy's Alberta Carbon Trunk Line (ACTL), a 240-kilometre pipeline that would capture CO2 from a bitumen upgrader and fertilizer plant for use in Enhanced Oil Recovery (EOR); Shell's Quest Project which will upgrade bitumen from Alberta's oil sands and store the CO2; Swan Hills Synfuels will use an in-situ coal gasification process to access deep coal seams to convert the coal to synthetic gas (syngas); TransAlta will use CCS technology to capture CO2 from an electricity plant and use it either for enhanced oil recovery or for permanent storage.

Alberta Environment Minister Rob Renner, left, and Climate Change Emissions Management Corporation chairman Eric Newell recently announced a number of projects that will receive funding for clean energy/carbon capture and storage research.

More information

To learn more about Alberta's CCS pursuit, visit www.energy.alberta.ca

University of Regina - leading carbon capture research on the Canadian Prairies

From fundamental research to commercialization, researchers at the University of Regina have been developing innovative post-combustion carbon capture technology for the past two decades.

www.uregina.ca/oee

It was clear to the University's handful of early pioneers that post-combustion capture (PCC) was the direction to pursue for carbon capture technology development, though in the late 1980s, the interest was in developing carbon capture as a source of CO_2 for enhanced oil recovery.

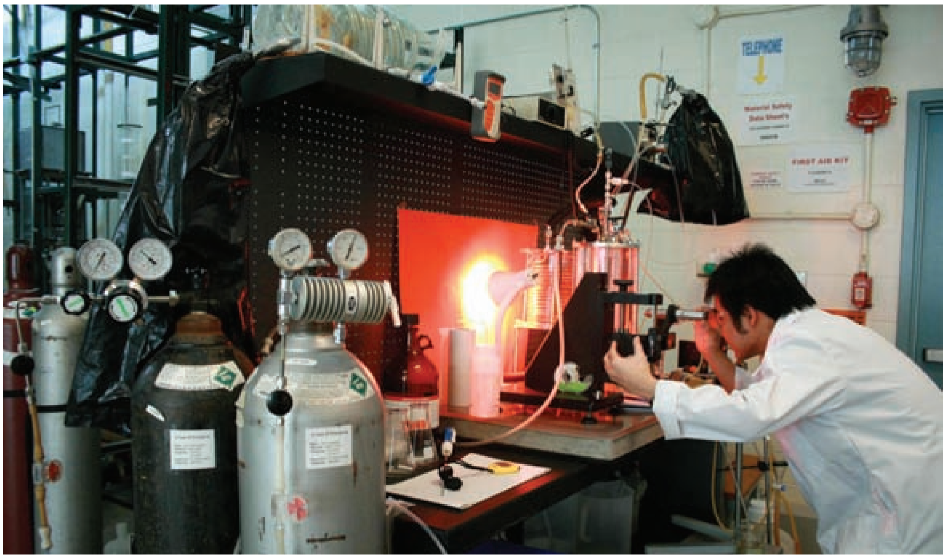
The ability to retrofit existing conventional coal-fired power plants with post-combustion capture capacity makes the technology particularly appealing to Canada and the USA as well as many other countries around the world and necessary for reducing global CO_2 emissions.

"Our researchers looked at the regional and global context and concluded that an easy retrofit was going to be necessary," said Dr. Paitoon Tontiwachwuthikul, Dean of the Faculty of Engineering and Applied Science at the University of Regina and co-founder of the University's International Test Centre for CO_2 Capture (ITC). "Over 40 per cent of the world's electricity is produced from coal-fired power plants. PCC provides an important solution to balancing energy demand with environmentally sustainable production methods."

Since 2001, the ITC has been conducting leading-edge carbon capture research and development in its state-of-the-art laboratories and pilot plants. The ITC is one of the best-equipped research facilities in North America and features equipment such as an X-Ray Diffractometer, Scanning Electron Microscope, Nuclear Magnetic Resonance Spectrometer, Gas Chromatography-Mass Spectrometer, and High Performance Liquid Chromatograph.

Researchers at the ITC study formulated/designer solvent development and testing, packing and membrane development, process configurations, corrosion studies, and simulation and modeling. "Our mission is to develop the most economic, effective, and versatile greenhouse gas reduction solutions possible," said Dr. Raphael Idem, Associate Dean of Research and one of the lead researchers at the ITC.

Fundamental and bench-scale carbon capture research developed in the labs is then followed by testing at the ITC's two pilot plants. The ITC's in-house facilities enable researchers to test their technologies in a



U of R researchers conduct work on laminar jet absorber to obtain formulated solvent's kinetic data

highly flexible, industry-relevant, CO_2 capture pilot plant. This plant processes flue gas from the combustion of natural gas.

Field testing and demonstration are conducted at the ITC's pre-commercial CO_2 capture plant, which captures CO_2 from the coal-fired Boundary Dam Power Station. This unit allows the ITC to test its CO_2 capture technology in a wide range of weather conditions, so that researchers can see how the technology performs whether it's -40°C or +40°C outside.

The technology also includes integrated artificial intelligence/knowledge-based process control and monitoring systems that help to increase operating efficiencies and further drive down operation costs associated with the capture process.

In addition, the ITC provides analytical services to industry and other research organizations, from chemical and elemental identification, characterization and quantification to analysis of degradation, decomposition, structural mutation, porosity, absorption, kinetics, and oxidation.

The carbon capture research being undertaken at the University of Regina is receiving international interest. In June, Doosan Power Systems announced the opening of its post combustion plant test facility at Renfrew, Scotland. This new plant will use Solvent Scrubbing Technology to capture CO_2 from coal-fired flue gases. This technology was developed by the ITC and licensed to Doosan Power Systems and HTC Purenergy. In the United States, a front end engineering and design (FEED) study is currently being carried out to outline the potential to use ITC capture technology on a coal fired power plant in North Dakota.

A commercial demonstration of CCS like the proposed plant in North Dakota is critical for CCS commercialization, and we need commercial CCS if we are to meet global carbon reduction targets.

"If you look at the International Energy Agency numbers, we're currently producing about 30 billion tons of CO_2 globally, and by 2050, we'll be up to 50 billion tons per year. Globally, we are increasing the concentration of CO_2 in the atmosphere by 2 parts per million or slightly more than 2 parts per million per year. This cannot go on indefinitely," said Dr. Malcolm Wilson, Director of the University's Office of Energy and Environment and co-founder of the ITC. "We need to make big cuts, which is why commercialization of CCS is essential."

The research in carbon capture at the ITC is complemented by a strong Petroleum Systems Engineering program in the Faculty of Engineering and Applied Science at the University of Regina. "The program has grown quickly and become one of the largest accredited petroleum engineering undergraduate programs in Canada," said Dr. Daoyong

(Tony) Yang, Petroleum Systems Engineering Program Chair.

Over the last decade, as a result of the establishment of the Petroleum Technology Research Centre (PTRC), the International Test Centre for CO2 Capture (ITC), and the International Performance Assessment Centre for Geologic Storage of CO2 (IPAC-CO2), high quality and focused research has been conducted with outstanding achievements: reservoir engineering, enhanced oil recovery suitable for medium and heavy oil reserves, well logging and well testing, drilling and production – all are applicable to the geological storage side of CCS, as well as the development of environmentally sustainable oil and gas production methods.

"At the U of R," said Dr. Tontiwachwuthikul, "We're building a full-chain of expertise in CCS that will provide the research and expertise to support commercial implementation of CCS not just in Saskatchewan and Canada, but around the world."

IPAC-CO2 - best practice for CO2 storage

IPAC-CO2 is a not-for-profit organization that was established to meet the needs of industry, regulators, and the public by providing independent, objective information, best practices, advice and assessment on geologic storage of carbon dioxide.

Majid Nasehi, senior project coordinator, IPAC-CO2

IPAC-CO2 Research inc. was established in 2009 with $14 million in funding from the government of Saskatchewan, Royal Dutch Shell and government of Canada.

Building upon Western Canada's considerable experience and skills in the subsurface oil and gas exploration and production, as well as the experience and expertise in the emerging field of Carbon Capture and Storage (CCS), IPAC-CO2 has set out to achieve its objective of supporting the development, commercialization and acceptance of CCS as a safe and effective technology for controlling CO2 emissions. IPAC-CO2 will achieve this objective by focusing its activities in three main areas:

1. Independent assessment and verification (assurance) of CO2 geological storage projects,
2. Development of standards for CCS, and
3. Global collaboration and exchange of knowledge

Risk assessment is a means for understanding technical parameters and cost implications of geologic storage. Comprehensive and independent risk assessments are necessary to gain broader public and regulatory acceptance for CCS as a preferred green house gas (GHG) mitigation and climate change management strategy.

In this respect, the goal of IPAC-CO2 is to facilitate project deployment by filling a niche in the CCS world of independent assessment and verification of CO2 storage projects at different stages including site screening and selection, design and construction, injection, closure, and post closure. It is not the intent of IPAC-CO2 to compete with commercial risk assessment organizations but to provide, through an independent third party performance confirmation and process reviews, the level of comfort needed by regulators, the public, and the industry that assessment of the risk of geological storage is being undertaken in an appropriate manner.

Currently, one of the most challenging aspects of any successful CCS project is securing the public acceptance and trust. IPAC-CO2's focus here as an independent organization is to create the transparency and the assurance needed for public and regulator acceptance and trust in the safety and efficiency of the project. If potential risks are exposed through a transparent decision making process that includes objective and independent research, full disclosure, and public education, widespread public acceptance of CCS will be possible and could result in more rapid deployment of CCS projects.

There are two fundamental things that facilitate transparency and enhance public acceptability. The first is common understanding of both the language and terminology surrounding CCS, and the second is trust that all of the factors that need to be considered in a safe, complete, and permanent storage process are recognized and are fully considered. To this end IPAC-CO2 is working to develop standards for the process as well as the terminology.

For standardizing CCS terminology to allow improved communication, IPAC-CO2 is engaging with the IEA Greenhouse Gas R&D Program to take the work undertaken by the IEA Green House Gas R&D program and Imperial College in London to develop a glossary of terminology for Risk Assessment for Geological Storage. This glossary will be converted into a wiki that will allow continuous editing and improvement.

IPAC-CO2 is also, in collaboration with the Canadian Standards Association, preparing standards for geological storage of CO2. The goal is to move quickly into the global standard arena. The standard will focus on geological storage of CO2 to minimize the risk of leakage, and is intended to establish requirements for the design, implementation, and management of storage sites including recommendations for screening and site selection, design, injection and operation, abandonment and long-term stewardship.

"IPAC-CO2 is a central access point for researchers to connect, learn and collaborate in the development of best practices, terminology, standards and tools for the mitigation of risk in geological storage of CO2. " - Majid Nasehi, senior project coordinator, IPAC-CO2

Once the first draft of the standard (or the seed document) is completed by IPAC-CO2 and CSA, it will be handed to a technical committee comprised of experts from universities, research institutes, government, and the industry. The approach taken here is to develop the standard based on best technology and industry practices, as well as the collective efforts, expertise, and experience of project developers, researchers, regulators and public.

The issues around CCS are global in nature and therefore, require a global approach. Several groups and partnerships around the world are conducting research into geological storage of CO2, with risk and performance assessment as two important components of the work. IPAC-CO2 seeks to connect and support this expertise

to build confidence for implementing CCS on a large scale.

From offices located in Regina, IPAC-CO2 is developing a global network of experts through participating universities and research agencies in different regions throughout the globe, to provide for knowledge transfer, capacity building and the ability to provide "conflict free" expertise. The global network will grow from regional centers IPAC-CO2 has in: Africa – South African National Energy Research Institute (SANERI), Australia – Cooperative Research Center for Greenhouse Gas Technologies (CO2CRC), Brazil – Brazilian Carbon Storage Research Center, Canada – Carbon Management Canada whose membership include University of Regina, University of Alberta, Dalhousie University and 18 other Canadian universities, China – North China Electric Power University, Europe – Imperial College in London, England, India – The Energy and Resources Institute (TERI), and USA – Colorado Energy Resource Institute (CERI).

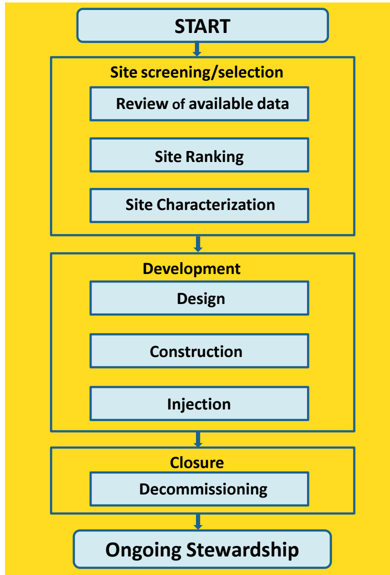
The aim is to build worldwide confidence for implementing CCS on a large scale by developing and providing a global body of knowledge for safe and effective geologic storage of CO2 through an internationally distributed network of experts. IPAC-CO2 is a central access point for researchers to connect, learn and collaborate in the development of best practices, terminology, standards and tools for the mitigation of risk in geological storage of CO2.

Independent Process Review

One of the most challenging aspects of any successful CCS project is currently public acceptance and trust.

Independent 3rd party performance confirmation and process reviews at different stages of the project including site screening and selection, design and construction, injection, closure, and post closure are necessary for all CO_2 storage projects. The goal is to facilitate the projects by providing the level of comfort required by the CO_2 producers, government, regulators, NGOs, and the public.

Involvement of an independent organization creates the transparency and the assurance needed for public and regulator acceptance and trust in the safety and efficiency of the storage project.



IPAC-CO2 offers its services to collaborate with the major projects in Canada and worldwide. This will be a mechanism also to provide knowledge back to IPAC-CO2 from commercial scale projects. This work could include the provision of experts to assist in risk reviews and the potential to undertake independent application of developing standards for the commercial projects.

For more information and to be kept updated on the activities of IPAC-CO2 visit: www.IPAC-CO2.com
or contact: info@ipac-co2.com

SaskPower Boundary Dam project

SaskPower is leading the development of one of the world's first and largest carbon capture and sequestration demonstration projects at the Boundary Dam Power Station in Estevan, Saskatchewan, Canada, and has awarded SNC-Lavalin an Engineer, Procure, and Construct (EPC) contract to build this CO2 capture system with Cansolv Technologies Inc. providing the process technology.

Andy Sundararajan, Manager, Business Development, SNC-Lavalin Inc.

SNC-Lavalin together with Cansolv will assist in commissioning and startup of the plant, pending SaskPower's final decision scheduled for before the end of 2010 as to whether or not to proceed with the full execution of the project.

The project will be fed by flue gasses from an existing 150MW lignite coal-fired unit that is being retrofitted for carbon capture, and will supply CO2 for enhanced oil recovery (EOR). Successful operation of this carbon capture technology may lead to the retrofit of the other units at the Boundary Dam Power Station, and aid in the commercialization of this technology.

This article provides an overview of the project and a brief summary of the development from concept to implementation, as well as some of the techniques being used by SNC-Lavalin in its implementation.

Based in Canada with operations worldwide, SNC-Lavalin is one of the leading engineering and construction groups in the world with a long track record delivering projects in sectors such as power, oil & gas, infrastructure & environment, and mining & metals.

With over 20,000 staff located worldwide, SNC-Lavalin is currently working on projects in over 100 countries. A unique exposure to both the power and oil & gas sectors places SNC-Lavalin in a unique position to design and execute CO2 capture projects. As a result of being awarded a competitive Front-End-Engineering Design contract in 2009, SNC-Lavalin's EPC proposal for the complete EPC of the facility was selected ahead of 2 other competitors, and accepted in early 2010 with anticipated project completion by the end of 2013.

Figure 1: CAD Overlay of Future Carbon Capture Plant

Technology provider Cansolv Technologies Inc. (CTI) are a wholly-owned subsidiary of Shell Global Solutions, and are providing the core SO2/CO2 removal technology for this project. Pioneers of the use of regenerable amines for selective bulk scrubbing of SO2 from oxidative flue gases, Cansolv brings a unique approach to the challenge of CO2 capture with their integrated SO2/CO2 technology offering.

SaskPower is the electrical utility for the Province of Saskatchewan located in central Canada. Its power generation portfolio includes three coal-fired power stations, seven hydroelectric stations, five natural gas stations and two wind facilities.

Project background

Carbon capture and sequestration technology in a modern power plant has the potential to reduce the carbon dioxide emissions to the atmosphere by approximately 90 percent. For this project, the resulting captured CO2 emissions will be compressed and transported through pipelines and sold for Enhanced Oil Recovery (EOR).

When completed, the SaskPower integrated carbon capture plant will capture over one million tones of CO2 per year, reflecting a 90% CO2 capture rate for the 150MW coal-fired unit. Additional benefits of the project include integration of an SO2 capture process that will provide feedstock for a 50 ton per day sulfuric acid plant. The project scope also includes the EPC of an acid plant, where SNC-Lavalin is a worldwide leader in sulfuric acid plant design.

The Boundary Dam Power Station is an aging asset in the SaskPower fleet, and the intent is to extend its life rather than replace the plant. The current projection is that the planned upgrades to the plant will extend its useful power production life by 30 years.

As part of this plant retrofit effort, a requirement to perform a Steam Turbine Generator replacement is imminent; by integrating the overall retrofit requirements with CO2 and SO2 capture implementation, savings will emerge versus an uncoordinated approach that would require significant rework of completed installations if carbon and sulfur capture were implemented separately.

Cansolv Integrated SO2 / CO2 Capture Technology – A Brief

Since SaskPower's Boundary Dam Station Unit 3 had no existing SO2 treatment, to retrofit the unit to capture carbon dioxide first required the addition of flue gas desulfurization (FGD) technology. In offering a single integrated system utilizing technologies that are very similar, Cansolv is uniquely able to integrate the SO2 and CO2 systems that work in unison within a single plant.

The Cansolv process incorporates FGD into the "front-end" of the treatment process, and maximizes efficiencies in alignment with SaskPower interests in maximizing heat integration and minimizing Low Pressure steam usage. One such example is the recovery of waste heat from the SO2 process, which will be utilized in the capture of CO2, lowering the overall parasitic energy load that is associated with typical amine-based carbon capture processes. The second form of internal heat integration is internal to the CO2 system itself.

The result is a single system that delivers two marketable by-products where captured SO2 is converted into sulfuric acid (H2SO4), and captured CO2 is compressed and used for Enhanced Oil Recovery. This contrasts with alternative FGD technologies such as wet limestone scrubbing, which produce a contaminated waste by-product that would add additional operating costs to the project.

At the heart of the Cansolv process are the patented Cansolv solvents: DS (SO2 scrubbing) and DC-103™ (CO2 capture). Each offers distinct advantages, including:

- Low regeneration energy;
- Low solvent degradation Fast kinetics: similar to primary amines;
- >99.9% SO2 and CO2 product purity;
- Produces Minimal effluent;
- Guaranteed removal efficiencies.

As a matter of sequence, flue gas is first sent to the SO2 absorber and then onto the CO2 absorber before being returned to the stack with zero SO2 and only 10% of the CO2 remaining. The gas is first quenched and sub-cooled in a Prescrubber section, which is located in the SO2 absorber. SO2 and CO2 are absorbed from the gas by contact with the Cansolv solvents through sections of structured mass transfer packing in the absorption towers. Lean cool amine is fed to the top of each Absorber Tower.

In each tower, as the absorbents flow down the column counter current to the feed gas, the pollutant is absorbed into the amine. The rich amine collects in the sump of the Absorber Tower and is pumped to the Regeneration Tower (or "Stripper"). Since the absorption of CO2 is an exothermic reaction, interstage cooling is employed mid-tower to remove this heat from the Absorber tower, thus maintaining efficiency.

The rich absorbent is pumped at a constant rate to the Regeneration Tower through a Lean/Rich Heat Exchanger that recovers sensible heat from the lean amine. A Reboiler is used to generate stripping steam which is injected into the bottom of the column. As the liquid solution flows down the tower, it meets the rising hot steam in sections of mass transfer packing where the heat reverses the absorption reaction and returns the SO2 and CO2 to the gas phase.

The gaseous product is carried overhead and cooled in the respective Stripper Condensers where most of the steam condenses. Water-saturated product (vapor) and product-saturated condensate are separated in the Stripper Overhead Accumulator and the condensate is returned to the top of the Stripper Tower as reflux. The CO22 product leaves the Stripper Overhead Accumulator and is delivered at positive pressure to the final dehydration and compression stage.

Engineering, Procurement, and Construction Challenges

With the core aspects of the novel carbon capture technology not yet fully defined to a commercial scale, SNC-Lavalin has met design challenges through innovative approaches. The size of the CO2 absorber to be utilized as part of the facility is on a scale that has not been implemented previously, but working with leading vendors, flow modeling and 3D reviews of the design have been successful in addressing unknowns and providing confidence to SaskPower and the project team who are now involved in engineering and procurement phases of the project.

Other scaling and technical challenges have benefited from implementing a full 3D CADD project execution using the advanced SmartPlant platform from Intergraph. By integrating Piping and Instrumentation Diagrams (as well as all multi-disciplinary engineering work) directly to the 3D model, end-to-end management of design through front-

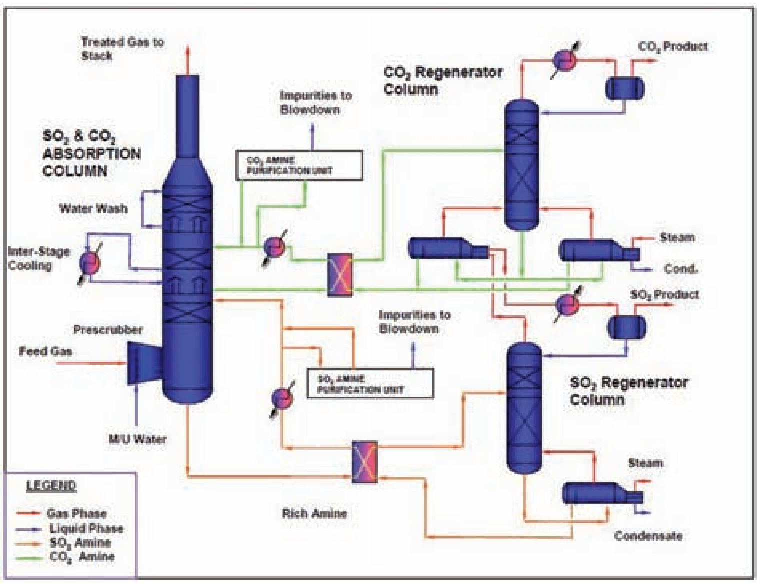


Figure 2: Flowsheet for Integrated Cansolv SO2/CO2 Process

Figure 3: 3D Model of SaskPower Carbon Capture Plant

end and detailed engineering has been maintained.

The benefits of this are reduced rework during construction where any field changes dramatically increase costs, and cause schedules to slip. Specifically, accurate identification of bulk materials and identification of potential clashes for routings of piping, equipment, and wiring are readily apparent during model reviews during the engineering phase of the project, where changes can be made when necessary with minimal impact.

Bulk materials which are identified and quantified via SmartPlant are downloaded electronically via a proprietary system developed by SNC-Lavalin called EMDS, directly into SNC-Lavalin's in-house project management system, PM+. The systems being utilized on the project have the positive effect of optimizing effort hours of engineering so that efficient use of available resources can be made.

Other aspects of the project execution where SaskPower is seeing benefits as a client is in attending and providing input into 30%, 60%, and 90% engineering completion model reviews. These reviews are managed by SNC-Lavalin with the technology provider and the client in attendance. Specific input is sought from SaskPower operations personnel as portions of the plant are viewed, with the intent that potential operations and maintenance issues are addressed immediately by the project team.

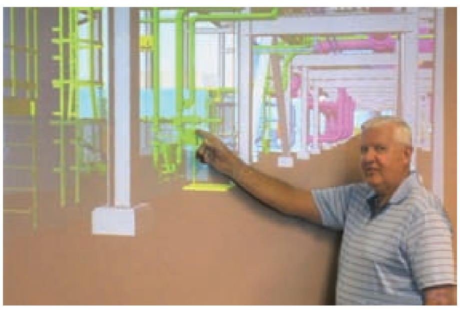


Figure 4: Project Director Walt Tomkiewicz walks through the 3D model during the 30% model review

These interactions are actively encouraged as part of SNC-Lavalin's design process that facilitates open communication with the client, resulting in positive changes being implemented across the entire model of the facility, leading to a design that SaskPower can be comfortable with. Similarly, the 3D model is also extremely helpful in Hazard and Operability (HAZOP) reviews of the plant where client personnel can see and fully appreciate the implications of control systems, and potential implications of hazardous situations that could arise, and implement the appropriate design changes to mitigate risks to future operators, and the plant itself. The SmartPlant 3D model may also be used for operator training prior to startup.

A great focus has also been placed on design for constructability throughout detailed engineering. The Saskatchewan construction and labor market is constrained, with the regional weather (notoriously harsh Prairie Winters) also reducing the calendar year that is suitable for construction. Areas where field construction can be optimized have been exploited to provide the project with potential schedule advantages.

Modularization of areas of the plant where possible has been emphasized, while accommodating restrictions imposed in transporting large modules and equipment to the landlocked location within the Central Canadian Province. Specific attention has been paid to modularizing utility racks, which will be shipped to the project site directly and interconnected in the field reducing rework, but requiring incredible precision and detail in the detailed engineering phase.

Sequencing of construction given the size and scope of equipment and modularized portions is also a big part of design efforts underway, with construction looming in early 2011.

SaskPower Competitive FEED Execution Model

In awarding the project, SaskPower benefited from first implementing a competitive Front-End Engineering Design (FEED) stage where three competing technology/EPC contractor teams were selected and awarded a mandate to develop a full FEED package, and EPC proposal to design and build a carbon capture facility.

With proven commercial scale CO2 solutions not available in the marketplace currently, this approach allowed competitors to undertake the necessary engineering to develop designs to a level to finalize costs for major equipment, piping, materials and construction and avoid heaping large amounts

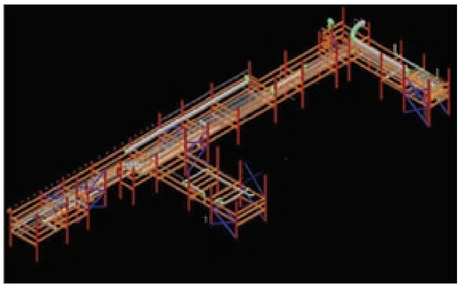


Figure 5: 3D Model of Modularized Utility Rack

of contingency on pricing making potential solutions uneconomic from the outset, and ensuring that the aspect of competition would also encourage creativity and efficiency in the designs and EPC proposals provided.

SaskPower's execution strategy has also reflected the reality of a project involving a novel scale-up of technology As with all similar projects that involve scaling up technologies, risks associated with warranties on the processes involved, and performance guarantees for the plant are hot button issues.

Risk allocation between a client, the technology vendor, and the EPC firm needs to be appropriately divided to help novel projects like this to move forward. SaskPower included time in its execution schedule to ensure that this significant contract negotiation issue was given sufficient focus without risking overall project schedule. For all such projects, this element should not be overlooked.

In summary, through the application of Cansolv's state of the art carbon capture technology and SNC-Lavalin's depth of expertise and advanced execution tools, all elements are in place to successfully implement one of the world's first and largest carbon capture facilities on behalf of SaskPower, and further the commercialization of this technology.

More information

For further information relating to this project, or related subjects, please contact:

Andy Sundararajan
Manager, Business Development
SNC-Lavalin Inc.
2275 Upper Middle Road East
Oakville, ON, Canada L6H 0C3
Tel no.: (289) 291-4295
email:
andy.sundararajan@snclavalin.com

Weyburn-Midale and Aquistore projects keeping Saskatchewan at the forefront of CCS research

During spring 2010, the Weyburn Oilfield in southeastern Saskatchewan surpassed 16 million tonnes of CO2 stored underground. Combined with the over 2 million tonnes underground at the adjacent Midale Field, more than 18 million tonnes of CO2 has been stored in the subsurface of Saskatchewan.

Norm Sacuta, Communications Manager, Petroleum Technology Research Centre

Currently, 8000 tonnes of new CO2 per day are injected into the two oil fields operated by Cenovus Energy and Apache Canada– delivered from the Dakota Gasification Company's coal gasification facility in North Dakota via a 320 km pipeline. Present annual injection is approximately 2.8 million tonnes of new CO2, more than double other current CCS projects.

When injection of CO2 was planned for the Weyburn oil field by then field operators, Pan Canadian (now Cenovus Energy of Calgary) in 2000, Dr. Malcolm Wilson of the Petroleum Technology Research Centre in Regina, Saskatchewan, suggested that the CO2 enhanced oil recovery operations offered the perfect opportunity to develop an accompanying measurement, monitoring and verification program to assure the CO2 stayed in place and was verifiable.

What began as purely an EOR operation transitioned quickly into a major research initiative, recognized by the International Energy Agency as an important program from which best practices could be developed to help other CO2-EOR operations transition into long-term storage. With the addition of Apache Canada's Midale field in 2005 to expand the area of study, a second phase of research, the IEA GHG Weyburn-Midale CO2 Monitoring and Storage Project, was initiated.

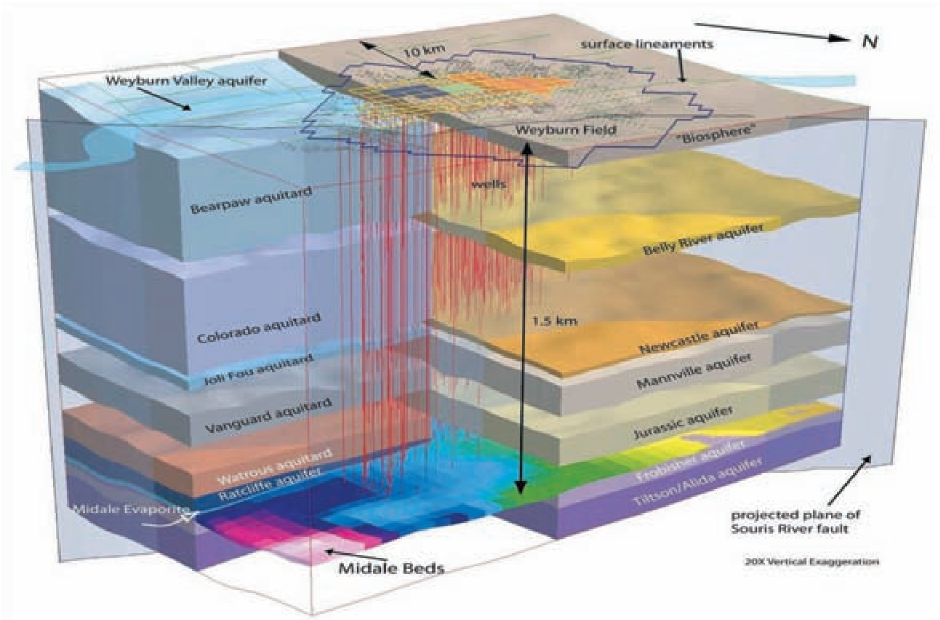


Figure 1: This geological model of the Weyburn Field depicts the layers of strata forming aquifers and aquitards above the formation. Wells are shown as vertical red lines. (Image courtesy of the PTRC)

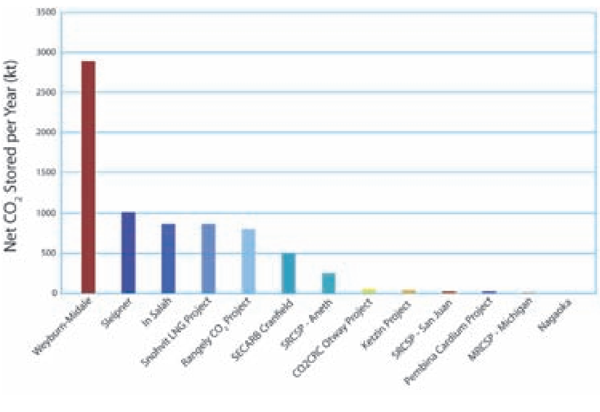


Table 1: Injection totals for selected CCS projects, globally (Chart courtesy of the International Energy Agency Greenhouse Gas R&D Programme)

Largest research project in the world looking at the geological storage of CO2

With no fewer than 10 corporate sponsors, as well as funding from the Governments of Canada, Saskatchewan, Alberta, Japan, and the United States (USDOE), the Weyburn-Midale project is an multi-million dollar research initiative that, after ten years of study, is coming to a conclusion.

The first phase of the project, completed in 2004, focused on themes, including: geological characterization; prediction, monitoring and verification of CO2 movements; CO2 storage capacity and distribution predictions and the application of economic limits; and long-term risk assessment of the storage site. This phase of work concluded that the geological setting is highly suitable for long-term storage. The second phase, which began in 2005, has sought to expand on the modeling and monitoring work performed in phase one, and explore other areas such as wellbore integrity, and conduct assessments of and non-technical components such as regulations and public communication.

"Geophysical monitoring is one area where the Weyburn-Midale researchers have made significant inroads in terms of identifying where the CO2 is, and much work is now focused on quantifying its distribution," notes the project's senior manager, Dr. Steve Whittaker."

Project is in its final year

With the project now approaching the end of its extensive monitoring and research program, the end deliverable – planned for late 2011 – is a Best Practices Manual that will help existing and planned EOR-CO2 operations in other jurisdictions to transition their

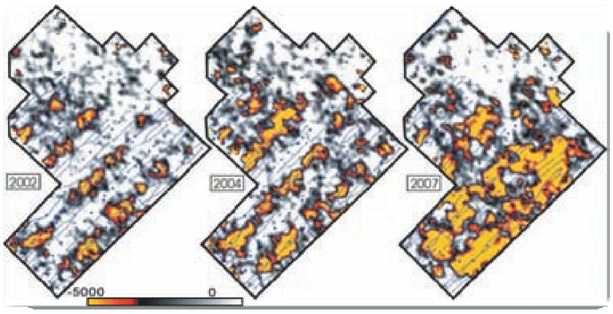


Figure 2: Using the year 2000 as a baseline, differences in seismic data collected in 2002, 2004 and 2007 are shown in the three images that map the expanse and location of the injected CO2 within the Weyburn reservoir. (Diagram courtesy of PTRC)

operations into long-term storage.

"The BPM," says Whittaker "will look at all aspects of storage and, given the rich data generated by the project, offer direction on how to best transition EOR into long-term storage. With research wrapping up by the end of March, 2011, we're optimistic we will have the manual produced before the end of that year."

New project in the works: Aquistore

Leveraging the experience gained in the Weyburn-Midale Project, the PTRC has been integral in the development of a new, integrated carbon capture and storage project that will look at the full value chain of CCS – from capture, to transport, injection, storage and monitoring – but this time storage will take place into a deep saline formation.

The Aquistore project, which involves the capture of CO2 from an oil refinery and transport via pipeline to an injection location, will see 550 tonnes of carbon dioxide per day delivered for injection starting in 2013.

"We're excited about the project," noted manager Kyle Worth, "because it may be the first operational CCS project involving deep saline storage. We are on target for drilling our injection well, and hope to have small sample injections of CO2 beginning in 2011."

A large amount of site characterization of the deep saline aquifer into which the CO2 will be injected has already been completed. The PTRC has involved a number of research organizations (some of which carry with them extensive knowledge used in the Weyburn-Midale project) to assist with the initial measurement and monitoring during the testing phase prior to large-scale injection.

"This project has generated significant industry and government interest," noted Dr. Whittaker, "just as Weyburn did. Our industry sponsors include the Consumers' Co-operative Refinery, which will be providing the CO2, Schlumberger, RITE, and SaskEnergy and Enbridge who will be building the pipeline. SaskPower has also joined the consortium, to complement its own extensive plans for its own CCS work such as the Boundary Dam project near Estevan."

Aquistore also has received Canadian federal funding from Sustainable Development Technology Canada and provincial funding from Saskatchewan Ministry of the Environment.

Public outreach and consultation a must

With CCS projects becoming more visible worldwide, and with the public interested in learning more about the technologies involved, the Aquistore project has been cognizant from the very beginning that every step of the project should involve public consultation and input. The project is now in discussions with local stakeholders regarding the program and identifying the preferred locations to generate feedback. Open houses are planned and a website to keep the public informed about all stages of the project is in design.

"We want to make sure Aquistore garners the sort of community support that the Weyburn-Midale project has enjoyed," notes Worth. "And that project has been a success, in part, because of the trust developed between the community, Cenovus and Apache, and the PTRC."

"We want the PTRC to be the leading edge in providing one possible solution to climate change," says Whittaker. "And Aquistore can provide that by taking one step past Weyburn-Midale to look at the whole value chain of a CCS project, right through from capture to long-term storage. This project could be the thin edge of the wedge of a whole new industry built around CCS."

Cows rest beside a CO2 injection well near Weyburn in southeastern Saskatchewan where more than 16 million tonnes of carbon dioxide have been stored underground

CCS legal and policy – July / Aug 2010

There is a storm brewing in UK waters at the moment which has the potential to profoundly affect the development of the regulations governing the UK's CCS infrastructure, says Calum Hughes, principal consultant in CCS regulation and policy at Yellow Wood Energy, as he continues his regular column covering developments in the legal and regulatory aspects of CCS.

calumhughes@yellowwoodenergy.com

The regulatory regime that currently governs access to offshore oil and gas transportation and processing infrastructure in UK waters has remained more or less unchanged for 35 years. Under this regime, parties seeking access to existing infrastructure, who consider the terms upon which they are being offered such access to be unreasonable, may refer their case to the Secretary of State for a determination of fair terms.

Similar referral options exist under different statutes for onshore and offshore pipelines and, as well as regulating access to existing infrastructure, allow third parties to require that new pipelines and associated equipment are specified and constructed in order that the capacity required by the third party is available provided that they are willing to pay the incremental cost of such capacity provision.

This regulatory model has been criticised by some as one which fails to yield infrastructure design which is economically optimal, but, while this may be true, advocates of the current model have cited in its defence that the Government determination option has never been called upon and, therefore, all parties must be content with the price and quantity of infrastructure access it engenders. Recently though, a rebuttal of this argument has been aired publicly: the apparent harmony may be due to the reticence of smaller, independent oil companies to risk raising the ire of their larger neighbours by exposing them to the potential embarrassment of a public censure, or worse, for abusing their dominant position.

Whatever the case in fact, the status quo is about to be tested; Endeavour International, being apparently unhappy at the amounts it is being charged by Nexen Petroleum for the use of the Scott Platform, has referred its case to DECC.

The offshore industry has a Code of Practice intended to lay down acceptable procedures and approaches for those entering into access negotiations and DECC has issued guidelines as to how it will carry out its determinations. However, neither of these are mandatory and, as the details of the tariff agreements in the subject case are not publicly available, one can only opine on what line will be taken by the Department in its determination and the tenor of the precedent it will set.

Whatever this proves to be, the referral seems to have brought to the fore a deficiency in the current oil and gas infrastructure access regulatory regime with regard to its role in providing developers of more marginal oil and gas fields with access to processing and transportation infrastructure at sufficiently commercially attractive rates.

This deficiency has apparently been recognised by the new coalition Government and the next Energy Bill, announced in May's Queen's Speech, will include provisions to: "ensure that North Sea infrastructure is available to all companies to ease the exploitation of smaller and more difficult oil and gas fields".

The relevance of all this to CCS is that DECC proposes to use the current oil and gas regulatory model as the basis for the regime that will be applied to CCS infrastructure in the UK. The obvious question raised by the recent events described above is whether a regulatory regime which is proving unsatisfactory for an industry where project economics are being squeezed is a sound basis for one where project economics are marginal from the outset.

Open access for new industry entrants to existing infrastructure is one key area for CCS and it is, accordingly, mandated in the European CCS Directive. The Directive must be transposed into Member State national law by June 2011 and DECC has stated that one of the reasons it finds the oil and gas model appealing for application to CCS is that it addresses the issue of mandated open access.

A satisfactory CCS regulatory framework must, however, also deliver adequate infrastructure capacity, and do so in an economically efficient manner. It has been recognised that the oil and gas regulatory model as it stands is not ideal in this regard and that it is likely to be even less suitable when applied to an industry in which there are even fewer drivers for the infrastructure developer to build in spare capacity and future revenue uncertainties are even greater.

DECC's proposed method of addressing this deficiency is to build in an 'open-season' period in the early stages of the infrastructure planning application procedure. During this period, the infrastructure developer is required to make details of its proposals publicly available and to allow adequate time, for those who may wish to have additional capacity or functionality incorporated into its designs, to enter into negotiations to have this done. It is hard to envisage, though, how an open-season alone might achieve DECC's aims. Consider, for example, an individual organisation, that currently predicts it will require, in order to remain competitive, a relatively modest amount of CO2 transportation capacity at some time in the next 15 years, but knows that the accuracy of these predictions are subject to the resolution of a number of policy decisions which are highly uncertain and have the potential to materially affect at which point its participation in CCS might be economically justifiable. Will this organisation decide to invest capital in the provision of that capacity now?

"Unless there are further changes made, in light of the recent experiences in the oil and gas industry, I doubt whether the first CCS regulatory model will stand the test of time as well as its oil and gas cousin". - Calum Hughes, Yellow Wood Energy

Whether further adjustments will be made to the oil and gas model, over and above those which have already been publicly mooted, as it is moulded into the final CCS regulations, is expected to become clearer over the next year or so. But, the nature of the CCS industry is materially different from that of oil and gas and, unless there are further changes made, in light of the recent experiences in the oil and gas industry, I doubt whether the first CCS regulatory model will stand the test of time as well as its oil and gas cousin. Well-advised project developers will consider the potential for changes to the regulatory regime when evaluating projects and add contingencies for this regulatory risk, a factor which will impact negatively on the likelihood of their projects achieving sanction.

The public perception of Carbon Capture and Storage

The University of Edinburgh and Scottish Carbon Capture & Storage are involved in both locally and globally oriented research on public perception. Activities range from a schools outreach program and a working bench top CCS model, to analysis of global engagement work.

www.sccs.org.uk

From the Netherlands to the U.S, public opposition can be, and has proven an obstacle to Carbon Capture and Storage (CCS) projects around the world. Opposition to these CCS projects has shown that there is a need to better understand local beliefs and to situate plans in the local context.

Royal Dutch Shell's CCS project close to Barendrecht has been postponed by at least three years as a result of pressures from the local electorate[1]. Despite local concern with the risks of CO2 injection and stated distrust in the developers, the national government has decided to permit the project[2].

Public opposition has also formed over plans to sequester CO2 beneath Greenville, Ohio and could feasibly prove an obstacle to plans for a new-build coal power plant with CCS at Hunterston, UK[3]. By contrast, the Total full-chain development at Lacq has gained very positive local support. It is therefore vital to understand why the public chooses to oppose or support CCS projects.

Pupils from Linlithgow Academy and Linlithgow Primary learn about CCS and climate change

The recent CCS roadmap published by the International Energy Agency (IEA)[4] argues that public opposition may arise when people feel that they have been treated unfairly in the planning process and when developers do not appear to be trustworthy. And while developers often wrongly assume that the local populace has a poor understanding of climate science it is still important that the link between CCS and global warming is made explicit to avoid confusion.

Rather than objecting to the merits of reducing CO2 emissions, opposition often arises from an incomplete understanding of the CCS chain, or because plans are not adapted to the local social context. On the other hand, local support is often not directly related to beliefs about CO2 sequestration and climate change, but is instead grounded in hopes for future employment and facilitated through successful relationship management. Relatively high public trust in Non Governmental Organisations (NGOs), compared with government and industry, means that NGOs are often in a favoured position to communicate the risks and benefits and to consider the concerns of local stakeholders.

Case study comparisons show that while issues of trust are generally important, in many cases the resulting mood is tempered by local socio-economic conditions. Public perception research from the USA concluded that a local population was more concerned with monetary compensation and employment, than with leakage risks from a potential CCS development and already had little trust in regulatory agencies and developers[5].

In the case of Barendrecht a different set of priorities - concerns with local risks - dominated the debate. In such cases, lessons on how to align the views of stakeholders who do not share the same perceptions of a planned development may be taken from technologies with a longer history such as wind energy projects.

SCCS at the University of Edinburgh currently has three outreach groups addressing different aspects of public perception. Programs like these and others are needed to help educate the public, and to help avoid clashes like those that have happened in other countries.

Outreach activities at the University of Edinburgh

CCS school's outreach program

With the help of Scottish Power and the Scottish Government, the Scottish Earth Science Education Forum (SESEF) has developed and successfully delivered a pilot outreach programme for secondary school students in Scotland. Since November 2009 students in schools around Longannet Power Station in Fife, have had a series of workshops delivered to them, as part of their national curriculum.

SESEF educators developed workshops where secondary school students were introduced to the concept of capturing carbon dioxide, why it could be a mitigation technology, the role of CCS in future energy generation and the risks involved. To ensure that the students understood the concept, these secondary school students then became the science educators and went to the local primary school to explain the concept of CCS to the primary school students. Students then went on, to present their ideas about CCS at

The Edinburgh International Science Festival and at Longannet Power Station.

For further information about SESEF and their CCS outreach program, please contact Catherine Morgan:
catherine.morgan@ed.ac.uk
or go to:
www.sesef.org.uk

CCS Interactive working desktop demonstration model

In collaboration with the School of Engineering and Scottish Carbon Capture & Storage, the FUSION outreach research group has designed and built an interactive CCS model (CCSI), which demonstrates the CCS chain from capture of CO2 to injection.

The desktop-sized interactive is built in three sections: a power station model, which produces a CO2-rich output; a working two-column pressure swing adsorption system, used to demonstrate the capture of the CO2 and the return of the cleaned flue gases; and a simulation of the transport and subsequent injection of the captured CO2 into a subsurface water-filled structure trap.

The SCI-FUN Roadshow, visiting secondary schools (11-14yrs) throughout Scotland in the coming academic year, will use the CCSI as part of a science show describing current areas of research at the University of Edinburgh. The interactive will also be used at science festivals and other public events, both independently and as part of a show describing aspects of climate change.

The software and hardware design of the CCSI allows it to be demonstrated in a variety of different ways, according to the level of knowledge of the target audience. Furthermore, as a fully-functioning CCS system, the exhibit will also be available for basic research into the characteristics of the adsorption process.

For further information about the CCS interactive exhibit, please contact Peter Reid: peter.reid@ed.ac.uk

SCCS Outreach

Members of the SCCS research team are also actively involved in outreach projects. As well involvement in the Edinburgh Science Festival, an internationally recognized annual event running for two weeks every spring, PhD students and postdocs have visited severals shcools and sixth forms across the country to talk about their research on CCS.

In addition, this year members of the SCCS were awarded a grant from the Edinburgh Beltane,a science communication initiative. The grant was to fund the design and construction of a traveling outreach project communicating CCS technology placed in the context of balancing energy demand with emissions reductions.

The project, named “CO2 Storage: Going Underground”, will be premiered at Our Dynamic Earth, a popular science museum in central Edinburgh, from the 8th to the 11th July 2010. Visitors will have the chance to learn all about the full CCS chain; why the technology was developed to how rocks can hold CO2, conceptualized with hourly demonstrations from FUSION’s CCSI.

Geophysical monitoring of CO2 will be communicated with the aid of audial material giving participants the chance to "hear" their way through a CO2 storage site. Perhaps most importantly, CCS technology will be placed within the CO2 reducing strategy for the UK. Visitors will, with the help of a brilliant game, have the chance to design their own "clean energy strategy", proposing the energy mixtures that they think are most suitable for the UK to adopt.

Three SCCS members will be present for all four days to assist with the games and concepts and to answer any questions or concerns of the public. Keep an eye on the SCCS website for a documentary movie of “CO2 Storage: Going Underground”!

These very practical examples are providing practical information to the interested public and schools. The content and type of message portrayed is influenced and informed by the social and technology reseach undertaken in SCCS, where Simon Shackley, Nils Markusson, Stuart Russell and others have academically anaysed project proposals worldwide and contributed to the writing of the IEAGHG roadmap4. Truly an example of rapid Knowledge Exchange into practical application.

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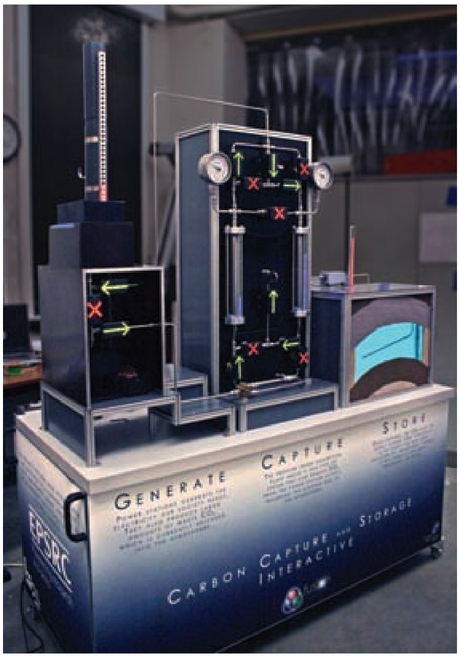

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SCCS is the largest carbon storage grouping in the UK, comprising in excess of 65 researchers in the University of Edinburgh, Heriot-Watt University and the British Geological Survey. SCCS is unique in its connected strength across the full CCS chain and unique in its biochar capability.

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Element Energy study on the potential for CCS in the North Sea

Element Energy, a UK-based low carbon energy consultancy, has recently completed the 'One North Sea' study funded by the UK Foreign and Commonwealth Office and Norwegian Ministry for Petroleum and Energy. The work was commissioned on behalf of the North Sea Basin Task Force, which is presently considering the report. **Harsh Pershad, Energy Consultant, Element Energy**

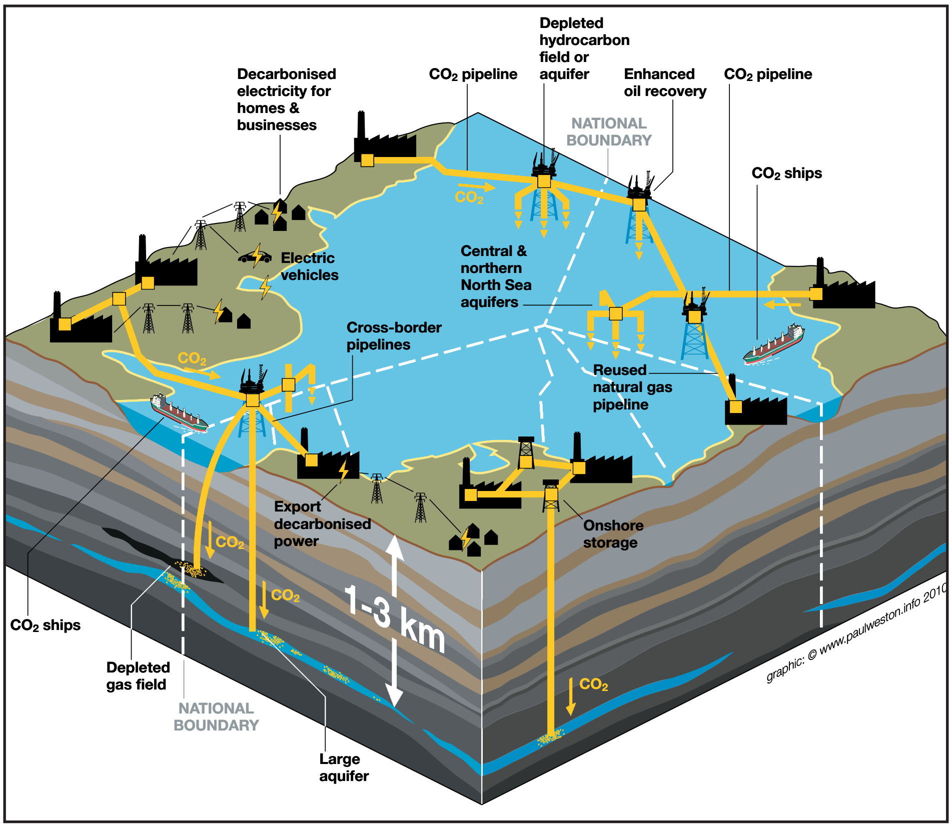
According to the report, Carbon Capture and Storage (CCS) in the North Sea countries could play an important role in European CO2 emissions abatement by 2030, with capture volumes above 270 million tonnes (Mt) CO2/year. By 2050 this could rise above 450 Mt CO2/year.

The combination of abundant CO2 storage capacity, clusters of CO2 sources, world class research institutes and commercial stakeholders, and a strong demonstration programme makes the North Sea countries natural leaders for the development and deployment of CCS technology in Europe.

Around fifty per cent of European CO2 storage potential is located under the North Sea. A large amount of predicted CCS demand is located within Germany, the Netherlands, Norway and the UK, the countries of the North Sea Basin Task Force.

The geographical clustering of sources and/or sinks gives opportunities to develop efficient transport and storage networks.

Many stakeholders around the North Sea have already developed visions for deploying safe, cost-effective and timely transport and storage infrastructure, although diverse but significant challenges have also emerged.



A One North Sea vision (illustration © www.paulweston.info)

The modelling and stakeholder consultation conducted demonstrate that:

• In a 'Very High' CCS scenario source 'clusters' or 'hubs' could be responsible for 80% of stored CO2 in 2030.

• Cross-border transport could become increasingly important beyond 2020 in scenarios with high CCS growth and/or where storage is restricted(for example, in onshore sinks). Cross border transport volumes could contribute up to 25% of overall CO2 flows in 2030.

• Uncertain CCS economic incentives, regulations and viability of specific sinks, and limited co-operation and organisation of stakeholders, work against private sector investment in capture and large scale transport and storage infrastructure.

• Uncertainties over capture demand and storage capacity also impede the public sector from making the clear commitments to CCS that the private sector requires.

Element Energy's analysis concludes that the rapid deployment of large scale low cost infrastructure by 2030 is technically achievable and is necessary for full deployment (e.g. the 'Very High' scenario described in this report which stores over 270 Mt CO2/year in 2030). However this would require a step change in co-operation in plan-

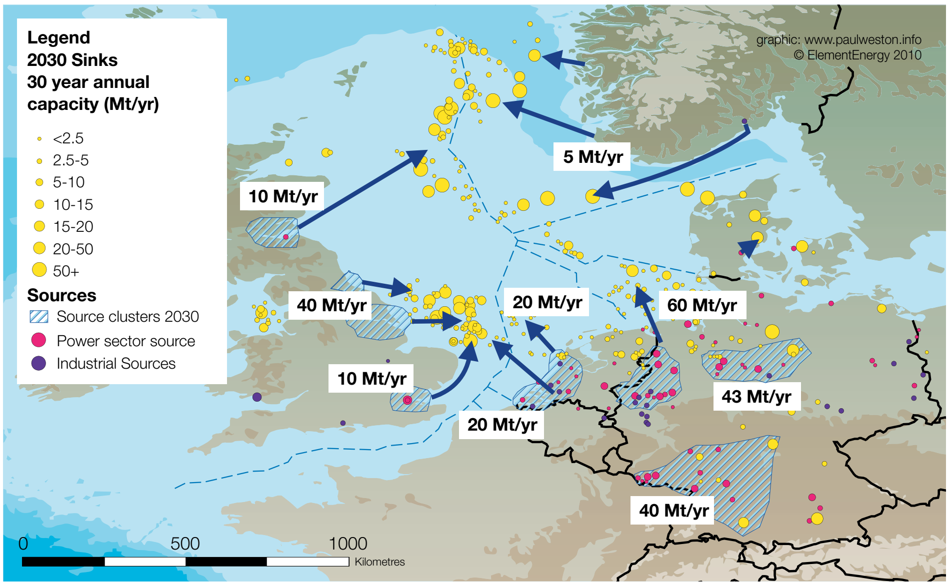
ning by numerous stakeholders, favourable economic conditions and CCS cost reduction.

With only modest further intervention, the market is likely to deliver only a few of the most straightforward CCS projects by 2030, storing up to 46 Mt CO2/year under the North Sea in a ‘Medium’ scenario. The shortfall between ‘Very High’ and ‘Medium’ scenarios would need to be met by other approaches to CO2 abatement.

The report makes a number of specific recommendations for key stakeholders. A general conclusion is that the focus for government and industry cooperation around the North Sea should be to:

1. Co-ordinate and lead the pre-commercial deployment of CCS in the period to 2020 and beyond.

2. Increase confidence in the location, volumes and reliability of sink capacity in and around the North Sea, and facilitate access to safe storage, for example through developing frameworks for managing cross-border CO2 flows.



CCS activity in the 'Very High' scenario in 2030 (illustration © www.paulweston.info)

3. Recognise shared interests, speak with one voice and act consistently, where possible, to promote the development of CCS.

The full report and appendix can be found at `www.element-energy.co.uk`

A CCS strategy for the new UK government

Chris Littlecott, senior policy adviser at the environmental thinktank Green Alliance, looks at the early actions of the new UK government, and identifies three key challenges that their CCS strategy must address.

We are exploring uncharted political territory, a prospect at once exciting but full of uncertainty. The new UK coalition has broken the mould of what we had come to take for granted as the standard process of forming a new government. Manifesto commitments have this time been blended into a new Liberal-Conservative cocktail.

And when it comes to the equally uncharted technology of CCS, we rightly have to ask whether this should be a cause for concern. Will there be differences of view between parties and ministers that threaten the progress that was made in fits and starts under the previous Labour government? Thankfully, the signs so far seem positive.

While there are many areas where the cooperation of the two parties will be severely tested, broad agreement on the climate and environment chapter of the coalition agreement was quickly reached. Only in respect to nuclear power has a potentially messy compromise been required.

Instead, the coalition agreement states that public sector investment in CCS technology will be prioritised, as will the introduction of an Emissions Performance Standard (EPS) and efforts to reform energy markets and carbon price signals. Box 1 sets out further details.

Ministers take the lead

On 8th July, the recently-created Office of CCS (OCCS) held its first senior stakeholder conference at which Secretary of State Chris Huhne announced the new Market Sounding exercise to identify projects that could receive government support via the levy mechanism agreed in the Energy Act 2010. In making clear that the new government’s aim is to make the UK first choice for CCS investment, Huhne also underscored that he and his Conservative ministers Charles Hendry and Greg Barker are “totally as one” when it comes to supporting CCS. Charles Hendry himself is well-respected across the CCS industry for his enduring interest and support for the technology, and has already made clear his desire to push DECC and OCCS into delivering at the scale and speed required.

With such strong ministerial backing, the challenge for DECC can therefore be conceived as one of ensuring CCS investment at scale. The creation of the OCCS under the Labour government, something that we at Green Alliance pushed hard to secure, now provides DECC with the institutional capacity required to deliver a detailed roadmap for CCS. This must find a route through the thicket of practical infrastructural challenges as well as fleshing out a package of finance and

BOX 1 – Coalition agreement on CCS and related issues

• We will continue public sector investment in carbon capture and storage (CCS) technology for four coal-fired power stations.

• We will establish an emissions performance standard that will prevent coal-fired power stations being built unless they are equipped with sufficient carbon capture and storage to meet the emissions performance standard.

• We will introduce a floor price for carbon, and make efforts to persuade the EU to move towards full auctioning of ETS permits.

• We will reform energy markets to deliver security of supply and investment in low carbon energy, and ensure fair competition including a review of the role of Ofgem.

regulation that can provide the necessary confidence to both industry and wider stakeholders. For achieving the government’s stated aim of making the UK the most attractive place to invest in CCS necessarily entails addressing concerns from environmental NGOs and other non-industry stakeholders.

For if a weakness is to be found in the

new government's exposition of its CCS priorities so far, it is in respect to the scope of its field of vision, which has focused almost exclusively on engaging with industry. While it is understandable that the new government wants to boost investor confidence in these fragile economic times, it cannot afford to limit its outreach to other stakeholders. Box 2 details how the UK can lead the way in this too.

BOX 2: UK must capitalise on conducive public acceptability conditions:

1. Public Acceptability. The silver lining of UK slowness on demonstration projects to date is that no public acceptability fight has needed to take place. It is indeed "the dog that is yet to bark". There is therefore an opportunity to proactively pre-empt such opposition before such a situation arises. A successful strategy will need to bring together strong message about the role of CCS in tackling climate change with location-specific arguments related to the economic benefits of particular projects. The safety of CO2 transport and storage will need to be addressed under both of these areas.

2. Pragmatic NGO engagement. UK NGOs have been willing to participate in discussions of CCS on a far more positive basis than anywhere else in the EU. NGOs will be of central importance in shaping public opinion about CCS, and can be key messengers in support of CCS demonstration projects. To take this opportunity, government policy needs to actively engage with the climate change concerns of NGOs and other key influencers from the academic community and advisers such as the Committee on Climate change. All of these perspectives need to be included in the new OCCS development forum.

Defining the strategy

With these opportunities in mind, and given the constrained economic circumstances faced by the UK exchequer, three key challenges stand out for action:

1. Think big, talk climate

Ministers need to set the terms of the discussion about CCS, clearly situating it as a climate mitigation measure, not an interesting technology experiment. After all, CCS only exists because of the imperative of acting on climate change. Too often in the past, the risk-minimisation approach taken by DECC failed to portray CCS as an integral option for decarbonising energy supply. While the UK Foreign Office has always been clear that CCS is a potentially game-changing technology that can unlock international political blockages to climate action, UK domestic delivery has lagged behind making this real.

Delivery of CCS demonstration projects will be made much easier within such a political framing, backed up by a policy framework that gives clarity on the timescale for the decarbonisation of UK energy supply, such as the Committee on Climate Change recommendation of a 2030 target. Broader reform of energy markets will help, but clear signals need to be sent now that low-carbon power investments must become the new norm. The coalition's commitment to defining an EPS can help to play that role.

2. Define direction of travel early

CCS project developers and investors will need to know the likely operating requirements for new plant across the lifetime of the asset, and, for those proposing to initially invest in only partial capture, the timescale within which full deployment of CCS technology will be required. Charles Hendry's recent public statements that he envisages an EPS as providing additional clarity to aid investment are therefore to be welcomed. The timescale for this is clear, with decisions needed over the same timescale as the negotiation of project financing for demonstration projects 2 to 4.

With limited public funding available, it will be of central importance to build the market at sufficient scale to foster the development of supply chains and the availability of different technology options. A combination of early decisions on EPS and a strategic infrastructure roadmap can combine with market reform measures to make CCS an attractive long-term industry, not a series of one-off projects.

At Green Alliance, our experience from the multi-stakeholder dialogue we convened in September 2009 alongside our partners at the CCSA is positive. Over two days of dialogue we clearly saw that a package of measures combining public finance with regulatory drivers offers the greatest chance of cross-sectoral support.

3. Secure the money

While there is no doubting the good intentions of DECC ministers and the OCCS team to make CCS happen, their enthusiasm is matched within government by the Treasury's reputation for ruthlessness. In particular the original CCS competition, the now-titled 'demo 1', will be in their sights given that the structure of the competition places a far greater burden on the government's balance sheet than subsequent projects 2 to 4.

Green Alliance has argued strongly during the past year that, despite its flaws, the CCS competition should be maintained as the fastest way to getting an early demonstration project underway in the UK. Senior Conservative politicians have taken this message on board, as seen by its inclusion in the coalition agreement. Now they must find the resolve to maintain its position against any Treasury pressure. Failure to do so would damage the UK's credibility in the eyes of CCS developers and investors, and seriously prejudice the timescale for making CCS commercially available for power sector decarbonisation. It would make the delivery of CCS more expensive rather than less.

Chris Littlecott, senior policy adviser, Green Alliance

Of course, there is clearly room for more creative approaches to project finance, including for projects 2-4. Indeed, the restraints on public spending should force greater attention on projects that can commit to up front emissions reductions, rather than leaving open a potentially larger bill for publically-financed retrofit of CCS at a later date. Cooperation between consortia rather than further rounds of competitive tendering should be encouraged. A CCS demonstration project for gas is also now imperative, as per the recommendation of the Committee on Climate Change in June 2010.

Furthermore, the government should consider alternative ways of making capital available and bringing down the risk to investors via its newly proposed Green Investment Bank. Now is the time to consider how it can incentivise the development of critical CCS infrastructure and leverage private sector investment in CO2 capture projects.

Conclusion

If the coalition government is to succeed on delivering its aim of making the UK first choice for investing in CCS it will have to address the challenges set out above: by framing the CCS challenge in strong climate terms; providing a policy framework that defines the timeline for power sector decarbonisation and the roadmap for CCS infrastructure development; and securing public sector finance to leverage private sector investment. In all of these it must engage with broader social stakeholders as well as the growing CCS industry. It's a big job, but one within the grasp of ministers and the new OCCS team. Green Alliance will be championing their efforts over the coming year. By early 2011 we will know whether the new government is on track.

Energy Institute - good practice for CCS

Carbon capture and storage (CCS), like any other area of the energy industry, will need to operate in a safe framework. Here, **Martin Maeso CEnv MEI, Technical Director, Energy Institute (EI)** highlights the EI's recent published guidelines on CCS and looks to further work needed in the future.

In 2006, the Department of Business, Enterprise and Regulatory Reform asked the Health & Safety Executive (HSE) to determine if there were any health and safety concerns relating to the deployment of large-scale carbon capture and storage (CCS) technology in the UK.

The HSE began a review of all aspects of the carbon capture and storage chain, from the various capture technologies through to the injection points on the offshore platforms. As part of this process it approached the Energy Institute (EI), as a technical forum for facilitating discussion on energy issues. It asked that the EI draw on its broad membership and initiate a discussion on the key health and safety issues around this emerging technology. Subsequently the EI identified a number of areas which it believed merited greater attention. These concerns can be split into two broad subject areas:

- modelling the dispersion of any leak of carbon dioxide appropriately; and
- ensuring good practice techniques from the industrial gases, chemicals and energy sectors is fed into the UK CCS industry.

To address these issues, the EI, working in partnership with the HSE and the Carbon Capture and Storage Association (CCSA), set up a Joint Industry Project (JIP), drawing together members from the oil and gas, power generation, pipeline and industrial gases sector, along with the Health & Safety Laboratory, the Environment Agency and HSE, to set about addressing the two key issues raised. The outputs from this activity are two guidance documents, both of which were published in May 2010.

Modelling and good practice

Appropriate hazard analysis is fundamental to assessing the risks for onshore pipelines and installations. The first guidance document, Technical guidance on hazard analysis for onshore carbon capture installations & onshore pipelines addresses concerns that the commercial models available to model the dispersion of gases are not validated for carbon dioxide, which has particular thermodynamic properties. As a result, any dispersion modelling using these commercial models may not be accurate and, without any validation, it would be impossible to use them with any confidence.

The document sets out an approach to produce a conservative set of analyses. Although there are comparatively few carbon dioxide pipelines in operation, the construction of these pipelines is not vastly dissimilar to many other conventional pipelines – thereby providing a large dataset of incident rates. So whilst current dispersion models are not exclusively designed for carbon dioxide, the EI guidance sets out methods to adapt the models for carbon dioxide. This has been the accepted approach in the industrial gases sector in relation to carbon dioxide and other cryogenic liquid installations. This approach has also been used to model carbon dioxide releases to assess environmental impact.

A second guidance document has been produced to ensure that the emerging CCS industry takes advantage of existing good practice in other sectors. Carbon dioxide has particular properties that affect the choice of materials and plant design. Although many of these issues are well understood by the industrial gases sector, they are not 'business as usual' for the CCS industry. For example, certain elastomers are commonly used in seals in the power generation and oil and gas industry, but cannot be used for carbon dioxide as they explode when rapidly depressurised. This guidance document, Good plant design and operation for onshore carbon capture installations and onshore pipelines – A recommended practice guidance document sets out the impact carbon dioxide has on aspects of plant design, operation and safety, and covers both onshore operations and offshore pipelines.

Work for the future

The methods recommended by the EI guidance are generally expected to be conservative, which may result in overestimating the hazard and thereby increasing mitigation unnecessarily. It has therefore been recommended that these conservative assumptions are used to screen CCS projects until there is a wider body of work to reduce the uncertainties. A number of potential future projects have also emerged from this process.

These include a recommendation to monitor moisture content of carbon dioxide systems to reduce pipeline corrosion, and specify what corrective action needs to be taken if excursions from the expected moisture content occur.

A suggestion for future work has also been made to reduce the uncertainties around the modelling of carbon dioxide, and in particular a better understanding of the solid/vapour transition.

At present, there is no database of carbon dioxide incidents. A further recommendation has been to set up an industry group to monitor these and to compile a database so that industry can learn from such incidents. Similarly, the need to share data on pipeline conditions has been highlighted so that collectively the industry can come to an agreed opinion on what maintenance and inspection requirements and schedules constitute best practice. This should allow both the general public and regulatory authorities to have confidence that carbon dioxide pipeline failures are no more than likely than, for example, natural gas pipeline failures.

The EI is also working with partners to develop training on carbon capture and storage. Vital to the success of CCS is the availability of appropriately skilled individuals. The Government's paper: Clean Coal: an industrial strategy for the development of carbon capture and storage across the UK estimates that by 2030 the CCS industry could employ up to 100,000 people across the UK. As well as working to ensure the industry has operational good practice at its disposal, the EI is working to ensure that those in the energy industry have access to good continuing professional development opportunities. The provision of training as well as good practice is one way of achieving this aim.

In undertaking its activity on CCS the EI works with and is supported by a wide range of organisations. These include the current members of the CCS JIP, the EI Technical Partners, CCSA and institutes such as the Global Carbon Capture and Storage Institute. This work is vital if the safety case is to be made for CCS schemes in future, and for the UK to fulfil its full potential in making a contribution to the development of CCS globally.

The EI's CCS guidance documents are available from:
www.energypublishing.org
If you would like to contribute to the EI's activity on CCS please contact Martin Maeso, EI Technical Director, at
e: mmaeso@energyinst.org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Policy, company and regulation news

Scottish and Southern to prepare CCS project in Peterhead

www.scottish-southern.co.uk

SSE (Scottish and Southern Energy) has announced plans to conduct carbon capture at its gas-fired power station at Peterhead, Scotland.

The project would demonstrate post-combustion capture of carbon dioxide emissions relating to the electricity output of the equivalent of 400MW of capacity. It would involve using an existing gas turbine, an existing steam turbine, an existing electricity network connection and land adjacent to the power station already owned by SSE.

Peterhead is well-located for transportation of carbon dioxide emissions and for subsequent storage, and a number of options for this are being considered. SSE will be discussing these, and the project in general, with the UK Government as part of its market-sounding exercise launched on 8 July by the Department of Energy and Climate Change (DECC).

The Energy Act 2010 provides for the creation of a financial incentive, funded by electricity suppliers, to support up to four CCS commercial-scale demonstration projects in the UK. The first project is being selected through the ongoing competition for a post-combustion capture project on a coal-fired power station.

In June 2010, the UK Committee on Climate Change (CCC), the independent body which advises the UK Government on setting carbon budgets, said that CCS equipment should be fitted to new gas-fired power stations. While its current policy, reflected in the Coalition Agreement, is to continue investment in CCS for four coal-fired power stations, the Government is considering the CCC's recommendations.

SSE is also developing plans for CCS on coal-fired power stations, and the Ferrybridge clean coal pilot project, a collaboration between SSE, Vattenfall, and Doosan Babcock in the UK, was awarded £6.3m by DECC, the Technology Strategy Board and Northern Way in April this year.

A different proposal to capture carbon dioxide emissions at Peterhead, and then export them to the North Sea for enhanced oil recovery and ultimate storage, was abandoned in 2007 because the then public policy framework did not allow adequate financial support.

"If long-term targets for reducing emissions are to be met, CCS technology is going to have to apply as widely as possible," commented Ian Marchant, Chief Executive of SSE. "This means gas-fired power stations as well as coal. I believe Peterhead represents the best site in the UK for a gas CCS project and I hope that our submission to the Government will be successful."

Scottish and Southern Energy's gas-fired power station at Peterhead, Scotland (Image ©SSE)

US-China collaboration fosters three projects

fossil.energy.gov

Three clean energy technology projects, one relating to CCS, have resulted from a 2009 agreement between the United States and China on a collaborative research effort.

The projects are a joint research effort between two U.S. Department of Energy (DOE) laboratories - the National Energy Technology Laboratory (NETL) and the Pacific Northwest National Laboratory (PNNL) - and the Chinese Academy of Sciences.

Directors from DOE's NETL and PNNL recently met with representatives of the Chinese Academy of Sciences to embark on multiple projects aimed at accelerating development and deployment of coal conversion, emissions capture, and carbon storage technologies.

The research team, called the Clean Energy Partnership, will undertake three projects as part of the agreement, which has a five-year term and emphasizes growing collaborative energy R&D between the two nations:

In the first project, researchers will evaluate converting an enhanced-oil-recovery site at China's Jiangsu oilfield into a geologic storage site for carbon dioxide emissions. Other geologic sites in China also will be evaluated to provide better understanding of the challenges and costs of deploying CCS in China.

The other two projects related to gasification of biomass and converting synthetic gas into natural gas.

$67 million for DOE research into CCS at exisiting coal power plants

Ten projects aimed at developing advanced technologies for capturing CO2 from coal combustion have been selected by the U.S. Department of Energy (DOE) under its Innovations for Existing Plants (IEP) Program.

Valued at approximately $67 million ($15 million in non-federal cost sharing) over three years, the projects are focused on reducing the "energy and efficiency penalties" associated with applying currently available carbon capture and storage (CCS) technologies to existing and new power plants.

CO2 power plant capture systems currently require large amounts of energy for their operation, resulting in decreased efficiency and reduced net power output when compared to plants without CCS technology.

These "penalties" can add as much as 80 percent to the cost of electricity for a new pulverized coal plant and about 35 percent to the cost of electricity for a new advanced gasification plant. The overall goal of research conducted by DOE's Office of Fossil Energy (FE) and managed by FE's National Energy Technology Laboratory (NETL) is to improve efficiencies and reduce these costs to less than 30 percent and 10 percent, respectively.

The Obama Administration has made a goal of developing cost-effective deployment of CCS technologies within 10 years, with an objective of bringing 5 to 10 commercial demonstration projects online by 2016.

The funding will focus on bench-scale and slipstream-scale development (0.5 to 5 MWe) and testing of advanced post-combustion CO2 capture technologies that include membranes, solvents, and solid sorbents.

For a full list of the projects see the DOE website.

Doosan Babcock test facility officially opened

www.doosanbabcock.com

HRH The Princess Royal has opened Doosan Babcock's post combustion plant test facility at Renfrew, Scotland.

The test facility features Post Combustion Carbon Capture (PCCC) technology and will be a key component in what the company says is now the world's largest carbon capture research facility.

The PCCC facility simulates the entire process of modern coal-fired power generation. It will burn real coals and biomass, and includes a range of gas clean-up systems, before carbon dioxide capture takes place.

The new facility uses Solvent Scrubbing Technology to capture CO2 from coal-fired flue gases, through a process of absorption and regeneration. Doosan Power Systems has been developing and will continue to develop this technology in partnership with the Canadian based HTC Purenergy and the University of Regina.

The company says it will be ready to deliver very low carbon emission power technology to its customers in both the UK and other global markets, as soon as the market for these products becomes available.

The new facility makes the Renfrew site a global centre for carbon capture research, complementing the OxyCoal Clean Combustion Test Facility, opened by Doosan Babcock in Renfrew, Scotland, in July 2009.

HRH The Princess Royal originally visited the Doosan Babcock site 10 years ago, and revisited Renfrew to meet employees on site and find out more about their activities in carbon capture.

HRH The Princess Royal opening Doosan Babcock's post combustion plant test facility at Renfrew, Scotland (Image: Doosan Babcock)

UK Government seeks industry input on CCS demo

www.decc.gov.uk

The UK Department of Energy and Climate Change (DECC) has announced the start of a 'market sounding process' for the UK's CCS Demonstration Programme.

DECC says it is intended to help the Department to explore workable options for the CCS demonstration project selection and funding processes, and learn about projects being considered by industry.

The market sounding period is expected to last approximately 2 months – from 08 July to 15 September.

DECC says it will use the information gathered during market sounding to inform the design of its selection process and project requirements.

It expects to launch the next stage of the demonstration program, funding up to four projects, by the end of 2010.

Element Energy study into CCS for gas

www.element-energy.co.uk

Element Energy has completed a study into the potential for CCS in the gas power and industrial sectors released.

The UK Committee on Climate Change (CCC) has indicated that in order to be on course to meet the 2050 target, the UK's power sector will need to be largely decarbonised by 2030. Focus to date has been on the more carbon intensive coal-fired power stations as options for CCS. As the debate develops, however, it is important to understand the opportunity for CCS on natural gas fired power generation and industry.

In June, the CCC published a report led by Element Energy Ltd, working with partners Carbon Counts and Amec, which quantifies:

- The technical potential for CCS in industry and the gas power sector.
- Plausible economic potentials (i.e. market sizes and breakdown) for CCS in industry and the gas power sector under a range of technology readiness, build rate and CO2 price scenarios.
- The impacts on CCGT-CCS economics in the context of high renewable penetration leading to low load factors for fossil plant

The report discusses the challenges posed by the need to operate flexibly, for example to manage intermittency caused by wind power. The report is useful for:

- energy and carbon market modellers
- investors, owners, operators, suppliers and customers of gas power stations and heavy industry
- developers of capture technologies
- public and private stakeholders considering the development of regional CO2 transport networks.

To obtain a copy of the report, please email Kate.Harland@element-energy.co.uk or Harsh.Pershad@element-energy.co.uk

Committee advises UK Government to consider CCS on gas

www.theccc.org.uk

The Committee on Climate Change (CCC) has advised UK Secretary of State for Energy and Climate Change, Chris Huhne, to consider extending the CCS competition to include gas as well as coal demonstration projects, and to consider extending the proposed Emissions Performance Standard to cover new gas plant added to the system from 2020.

A letter, from Lord Adair Turner, recommends a coherent approach to all conventional fossil fuel generation (i.e. coal and gas), building on the current – coal focused – approach.

Given new evidence on the potential competitiveness of gas CCS with other forms of low carbon generation, and the very limited international effort to develop this technology, the Committee suggests that serious consideration should be given to funding at least one gas CCS demonstration project as part of the four coal CCS demonstration projects committed to in the Coalition Agreement.

The Committee's analysis shows that

the path to meeting the UK's 2050 target to reduce emissions by 80% requires that the power sector is largely decarbonised in the period to 2030 (e.g. average emissions should be around 100 g/kWh in 2030, compared to around 500 g/kWh today).

Given the need to decarbonise the power sector in the period to 2030, and therefore the very limited scope for investment in conventional gas generation beyond 2020, an Emissions Performance Standard that would effectively require any new gas plant beyond 2020 to be fitted with CCS should also seriously be considered, the letter says.

The Committee acknowledges the need for investment in conventional gas fired generation to maintain security of supply over the next ten years, and propose that the Emissions Performance Standard should not apply to plant added to the system before 2020.

"In order to meet our climate change targets, we need to invest in low carbon power generation. New conventional gas generation is required to maintain security of supply over the next ten years. Beyond that, further investment in conventional gas would conflict with required decarbonisation of the power sector by 2030," explains Chief Executive David Kennedy.

"We are recommending that investment in conventional gas after 2020 should be ruled out, and that this should be replaced with investment in gas CCS and other low carbon technologies. We are making the recommendation now given the need to move forward with the second CCS competition and to promote debate around proposed new energy legislation."

Comments

"The Committee on Climate Change has hit the nail firmly on the head: we cannot meet our country's climate change targets unless we decarbonise the power sector and we cannot do this without carbon capture and storage (CCS) on gas as well as coal fired power plants," said Dr Jeff Chapman, Chief Executive of the CCSA.

"We absolutely support the development of CCS for gas generation, but this cannot be at the expense of decarbonising coal generation. The CCSA recommends the Government commits to support additional projects, outside the current competition, specifically to develop CCS for application on gas fired power stations."

"The simple facts are these: we need new power stations in the UK to replace the retiring coal and nuclear fleet, the importance of having coal as well as gas plant to ensure reliable electricity supplies is well documented, and we need to equip these new plants with CCS to move to a low carbon economy. The sooner we get on with it, the better."

Commenting on the Committee's recommendation to implement an Emissions Performance Standard to mandate CCS on gas generation, Dr Chapman suggested:

"An Emissions Performance Standard could be useful in developing CCS on gas and coal generation but it cannot be implemented in isolation. We need an appropriate market structure, which balances fossil fuels with CCS, wind power and nuclear to decarbonise the power sector, as promoted by the Committee on Climate Change."

DOE extends funding for three projects

www.fossil.energy.gov

Three Recovery Act funded projects in Texas, Illinois, and Louisiana have been selected by the U.S. Department of Energy (DOE) to continue testing large-scale CCS from industrial sources.

In 2009, the industrial sector accounted for slightly more than one-quarter of total U.S. CO2 emissions of 5,405 million metric tons from energy consumption, according to data from DOE's Energy Information Administration. The three projects are expected to capture and store a total of 6.5 million tons of CO2 per year, and increase domestic production of oil by more than 10 million barrels of oil per year by the end of the demonstration period in September 2015.

Following successful completion of their Phase 1 activities, the three projects will now enter into Phase 2 for design, construction, and operation. The second phase of these projects includes $612million in Recovery Act funding and $368 million in private sector cost-sharing for a total investment of $980 million. The projects will be managed by the Office of Fossil Energy's National Energy Technology Laboratory (NETL).

Potential additional applications for funding of large-scale industrial carbon capture and storage projects are pending further clarification and review.

The selected projects are:

* Air Products & Chemicals, Inc. (Allentown, Pa.)—Air Products will partner with Denbury Onshore LLC to capture and sequester 1 million tons of CO2 per year from existing steam-methane reformers in Port Arthur, Texas, starting in November 2012.

The CO2 will be delivered via a 12-mile connector pipeline to an existing Denbury interstate CO2 pipeline and sequestered via use for enhanced oil recovery in the West Hastings oilfield.

The project team includes Air Products & Chemicals, Denbury Onshore LLC, the University of Texas Bureau of Economic Geology, and Valero Energy Corporation. (DOE share: $253 million)

* Archer Daniels Midland Company (Decatur, Ill.)—The project will capture and sequester 1 million tons of CO2 per year from an existing ethanol plant in Illinois, starting in August 2012. The CO2 will be sequestered in the Mt. Simon Sandstone, a well-characterized saline reservoir located about one mile from the plant.

The project team includes Archer Daniels Midland, Schlumberger Carbon Services, and the Illinois State Geological Survey. (DOE share: $99 million)

* Leucadia Energy, LLC (New York, N.Y.)—Leucadia and Denbury Onshore LLC will capture and sequester 4.5 million tons of CO2 per year from a new methanol plant in Lake Charles, La. The CO2 will be delivered via a 12-mile connector pipeline to an existing Denbury interstate CO2 pipeline and sequestered via use for enhanced oil recovery in the West Hastings oilfield, starting in April 2014.

The project team includes Leucadia Energy, Denbury, General Electric, Haldor Topsoe, Black & Veatch, Turner Industries, and The University of Texas Bureau of Economic Geology. (DOE share: $260 million)

CO2Sense Yorkshire launches online CCS network for region

www.co2sense.org.uk

An online network has been set up to help businesses interested in the Yorkshire and Humber CCS cluster in the UK to find out what's new and exchange ideas with other companies.

The Carbon, Capture and Storage (CCS) Supply Chain network has been set up for organisations who may be interested in supplying products and services to develop this technology within the region.

It is one of over 20 public and private networks that focus on other areas, such as recycling, renewable energy, food and drink, plastics and local authority waste management.

The interactive forums compliment CO2Sense's website by allowing people to take part in online discussions, and find solutions to common industry problems. They also meet CO2Sense's objectives of lowering the region's carbon footprint, and helping businesses to reduce costs and encourage growth.

CO2Sense Yorkshire is a business support and market development programme funded by Yorkshire Forward and the European Regional Development Fund.

Calera - using CO2 to make useful materials

Calera captures carbon in a different way from typical gas separation technologies: permanently converting CO2 emissions to CO3 and producing carbon-negative building materials such as cement and concrete.

Brent Constantz, CEO, Calera

The heart of the Calera process is the technology associated with carbon capture and conversion to stable solid minerals. We refer to this new process as Mineralization via Aqueous Precipitation, or MAP™ for short. In its simplest form MAP involves contacting gas from the power plant with water. The water chemistry is controlled such that the carbon dioxide in the power plant gas is absorbed into the water and reacts with the water hardness to form solid mineral carbonates and bicarbonates, which are very similar to finely disseminated 'whitings' seen in tropical oceans at mid-day.

These solid mineral carbonates and bicarbonates now contain carbon dioxide that would have been emitted into the air. After removal from the water and with further processing, the solids have value in a number of construction applications. The versatility of MAP also allows the generation of soluble and suspended bicarbonates, using half the amount of input materials, but still converting carbon dioxide into aqueous solution that can be injected underground for incorporation into geologic record without the need for a structural trap or the risk of leakage of carbon dioxide.

Many of the crystallographic forms Calera synthesizes are previously undescribed, or poorly known. These novel 'polymorphs' make it possible to produce high reactive cements, and aggregate precursors, with bulk chemistries that would usually be relatively inert.

Akin to portland cement and aggregate which derive from mining operations in quarries and subsequent processing, the precise stoichiometry of Calera's cements and aggregates will vary somewhat by site and will include other trace/minor components. In particular, many trace components will be captured from the flue gas such as sulfur oxides and mercury and will be incorporated into the solid phase as insoluble sulfates and carbonates.

After removal from the water and appropriate processing, the solids have value in a number of construction applications. The versatility of MAP also allows the generation of bicarbonates, using half the amount of input materials but still mineralizing carbon dioxide into an aqueous solution that can be injected underground for storage without the possibility of leakage of carbon dioxide.

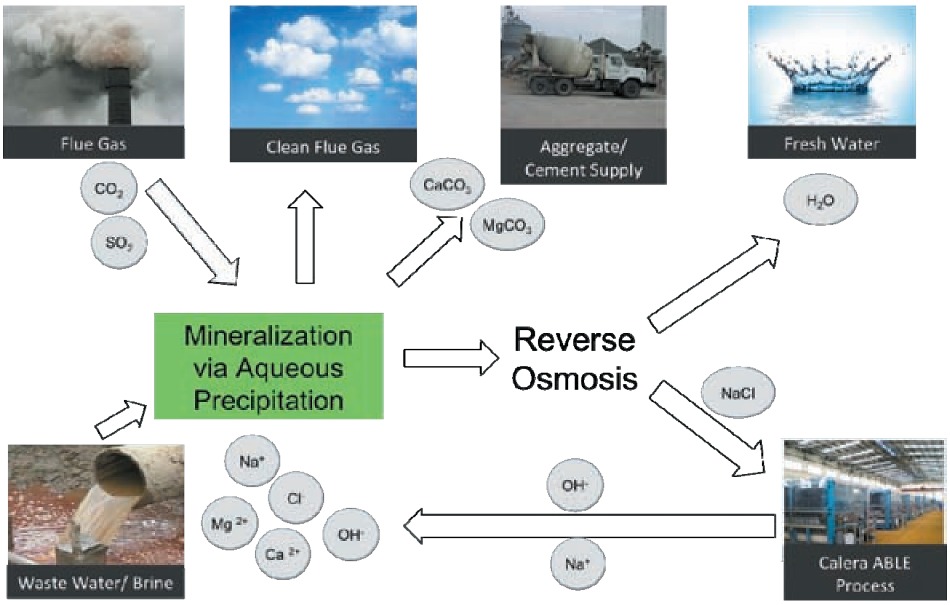


Figure 1 Schematic of the MAP (Mineralization via Aqueous Precipitation) process

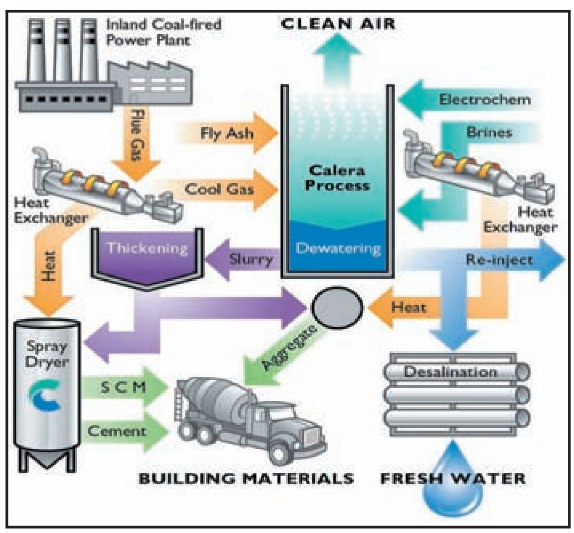
Depending on location and product offering, a Calera proprietary high-efficiency electrochemical process called Alkalinity Based on Low Energy (ABLETM) is employed to produce NaOH and HCl using only salt and electricity:

$$NaCl + H2O \text{ -> } NaOH + HCl$$

In locations with water shortage, the process water streams leaving the dewatering operations may be desalinated in a reverse or forward osmosis with reduced cost and energy demand, owing to the chemical removal of Ca/Mg (precipitated softening in the MAP process) as well as shared pretreatment and discharge operations. The salt-enriched RO concentrate can be utilized in the ABLE process operations.

The Calera process has been proven to be robust and is not very sensitive to flue gas carbon dioxide composition. Other carbon capture technologies require pre-scrubbing of sulfur dioxide to very low levels prior to capture of carbon dioxide. In contrast, MAP actually removes sulfur dioxide compounds and other air pollutants using the same basic absorption and conversion techniques as used for carbon dioxide.

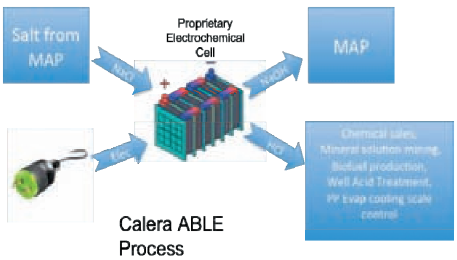
Calera has conducted multi-pollutant testing with the process operated on flue gas from a wide variety of coals in the pilot scale plant. These studies have shown that MAP removes most trace metal emissions to non-detect levels using U.S. EPA reference methods; captures mercury with high removal efficiency and incorporates the mercury into



the carbonate matrix in a nonleachable form, and captures high levels of acid gas by absorption. All trace elements assayed in the supernatant water are below water discharge limits (U.S.: NPDES). Our pollutants are incorporated into the minerals we form and the testing performed demonstrates non-detectable levels of these pollutants are available, which meets EPA standards using standard EPA tests.

Based upon evaluations conducted on the retrofit of existing coal fired plants, the expected capital cost for installing a traditional Flue Gas Desulfurization (FGD) for sulfur dioxide control is in the range of \$450/kW. Since the Calera MAP technology captures both sulfur dioxide and carbon dioxide, the retrofit of a 500 MW coal fired facility with MAP would offset approximately \$225 million that would have been necessary to control sulfur dioxide alone. Since sulfur interferes with the carbon dioxide absorption reaction for other technologies such as amine scrubbers, the true cost of installing these systems are much higher in a retrofit of existing coal plants.

As mentioned earlier one of the revolutionary breakthroughs that have been made at Calera is the ability to generate sodium hydroxide at lower energy than other competing technologies. Calera's ABLE process uses an electrochemistry process to split salt to form an alkaline solution and acid at one-third to one-fifth of the energy of the current state-of-the-art. Anywhere salt and electricity are available we can make alkalinity for the MAP process.



What is unique about the process is that it builds on advances in chlor-alkali and fuel cell design to reduce the energy requirements for the process. We have demonstrated the continuous operation at laboratory scale and have constructed a 1-ton per day pilot scale system at our facility in Moss Landing.

We have teamed with the world's largest supplier of advanced electrochemical cell components to accelerate the scale-up of the technology. Once the pilot scale optimization is complete, the process is readily scalable to full scale through the addition of more cell stacks. The product of our process is caustic (sodium hydroxide) and acid (hydrochloric acid). The caustic is used directly in the MAP process as a source of alkalinity.

If our ABLE process is required to supplement the natural alkalinity at a host site, aqueous HCl would be co-produced. This would be used in a number of proprietary processes under development at Calera with the remainder being sold into the merchant market. Current industrial uses for aqueous HCl include uses in the food, biofuel and pharmaceutical industries, steel pickling, and the production of organic chemicals such as chloromethane. The acid can also be used in oil well acidizing or brine production with underground injection and incorporation into the geologic record.

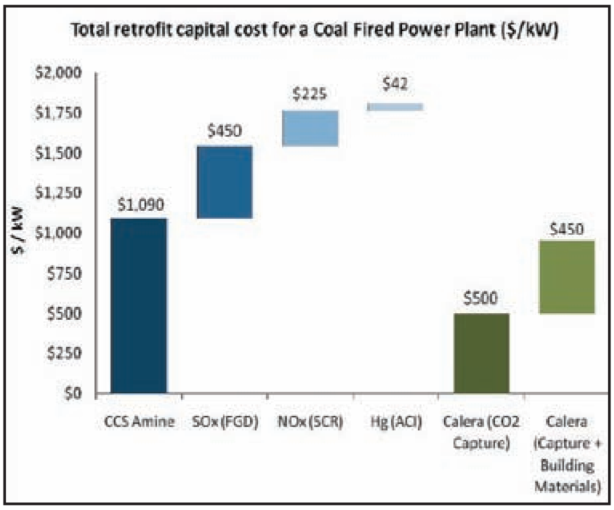
Fly ash is an extremely valuable resource that can be used as a source of alkalinity and cations for the Calera process. It is in keeping with the spirit of Calera to make use of this material to greatest extent possible. Calera can use both the as-produced (real time) fly ash and that stored on site at a power plant. The need to store as produced material is eliminated and the danger associated with storing ash on site can be remediated.

Calera has successfully used fly ash in our process in the laboratory and at the pilot plant scale. After passing through the Calera process, the silica from the fly ash remains available and can be used in the production of Calera SCM and aggregates.

Calera has the potential to foster significant environmental benefits:

When one ton of coal is burned, approximately 2.5 tons of carbon dioxide are produced. Using the MAP process, Calera makes two tons of product from every ton of carbon dioxide captured. That means we generate 1 x 2.5 x 2 = 5 tons of product per ton of coal burned.

So, for every one ton of coal mined, we can avoid mining five tons of limestone and aggregate. If we make supplemental cementitious materials there is an avoidance of 7.5 tons of limestone mining that would have been required in the cement process to produce 5 tons of cement. In this case, the Calera process for SCM production reduces mining by over 85%.



Cost comparison of the Calera process

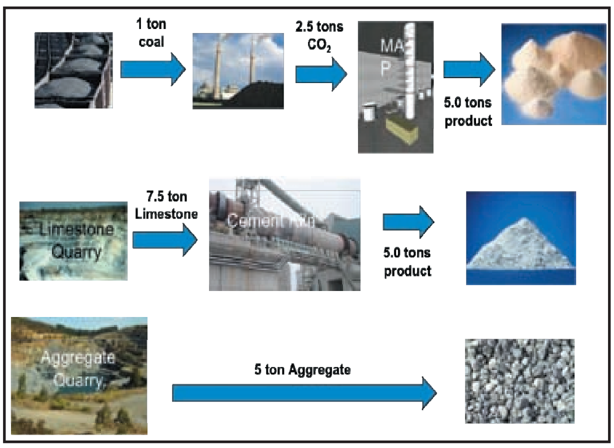
The Environmental Impact of Reduced Mining

Over 32 billion tons of aggregate are mined out of the Earth every year; 2/3rds of it is limestone used in concrete and asphalt. Another 4 billion tons of limestone are mined every year to make portland cement. Calera's process has the potential to replace between 24 and 36 billion tons of mining every year; this is 4 to 6 times the total amount of coal that is mined every year. Every ton of coal burned produces 2.5 tons of carbon dioxide which makes 5 tons of Calera SCM or aggregate.

Avoided Mining

Each ton of coal mined produces approximately five tons of SCM and aggregate, thus reducing mining for cement and aggregates by more than 80%.

Calera has been awarded funding for Carbon Capture and Sequestration activities from both the Department of Energy (DOE) and the California Energy Commission (CEC). We are moving forward quickly with significant technological advances at our Moss Landing Pilot Facility. The design and scale-up for this 10 MWe coal equivalent



carbon capture demonstration facility has capture rates above 85% of carbon dioxide and 95% of SO2.

The Moss Landing Facility represents Calera's first complete demonstration of the formation of metastable calcium and magnesium carbonate and bicarbonate minerals by capturing carbon dioxide from flue gas and converting the gas to solid minerals that can be sold as carbon-negative building materials. Calera will work with Bechtel to design and build cement plants, plans to open its first commercial plant next year. The company is in talks with Dynegy and a utility in Pennsylvania and has received grants from the Australian government to build a cement plant next to a coal plant in the state of Victoria.

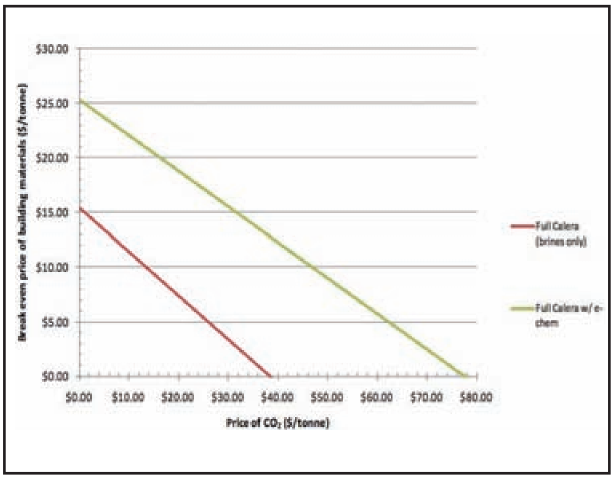
While we believe many solutions will be needed to address global climate change, Calera does more to reduce carbon dioxide emissions and is more financially attractive than any alternative carbon capture solution. Most other carbon dioxide capture technologies must overcome high costs and can consume above 35% of the host plant's electricity generating capacity[1].

Calera is unique among carbon capture solutions because, in most markets, revenues from the capture and sequestration of carbon dioxide, SOx, Mercury, other heavy metals, and fly ash remediation, as well as sales of the building materials and water, allow Calera to generate a profit with an attractive return on capital, while increasing the value of the carbon emitting plant.

Each point emitter site is different. Our evaluation process assesses the optimal configuration and go-to-market strategy for each location. This analysis determines the technology applied, the specific configuration, and the best mix of products and services offered.

The Calera story began in 1984, when Brent Constantz was a graduate student at the University of California at Santa Cruz. Constantz had a coveted National Science Foundation Predoctoral Fellowship grant, entitled "The Skeletal Ultrastructure of Scleractinian Corals", allowing him to study coral growth mechanisms in the Caribbean and the Indo-Pacific, as well as the deep sea and temperate latitudes. His insights about the physiochemically-dominated skeletogentic mechanism of reef coral led to Norian SRS, a market leading biomimetic biomineral bone cement used today in most operating rooms that perform orthopedic surgery.

Before he became aware of the global epidemic of osteoporosis, he had been interested in co-opting coral growth mechanisms for creating large structures in tropical oceans out of 'mother-of-pearl' or synthetic limestone. His vision was that these mechanisms would be lifted out of the sea in modules and assembled into massive structures in the built environment, like buildings and bridges.



Break even price of building materials as a function of CO2 price

Constantz started his college career in 1976 at U.C Berkeley in architecture, mostly to play on their NCAA championship water polo team. He transferred to UC Santa Barbara in 1978 to a double major in Aquatic Biology and Geological Science, after seeing scanning electron micrographs of the elaborate mineralized structures of diatoms (siliceous marine plants), which he saw as the most fantastic architecture.

During the two decades (1987 – 2007) following his post-doctoral studies at the USGS and Fulbright at the Weizmann Institute, his primary attention was focused on medical applications of biomineralization. Having initially met Vinod Khosla in 1987, and having learned of Khosla's interest in clean technology, Constantz contacted Khosla in 2007 with his idea about a new "green cement" to replace the carbon-intensive Portland cement, the third largest source of anthropogenic carbon dioxide.

Khosla saw the value of the idea immediately and funded Calera after a couple of meetings, without even a business plan or slide presentation. Within a few months, Constantz had assembled a team that was making carbonate cements from seawater, hauled over from Santa Cruz to their facility in Los Gatos in a water trailer. In October 2007, while Khosla was visiting the Los Gatos laboratory, the team noted that lack of carbon dioxide in the seawater was limiting the reaction, and there was a need for more carbon dioxide. An experiment was in progress, bubbling carbon dioxide through the seawater, and it was noted that the yield increased eight-fold. Constantz turned to Khosla and asked, "Where can we get large quantities of carbon?"

CEO Brent Constantz walking across the upper platform of the electrochemical portion of the plant

1 The Future of Coal (MIT, 2007) reports that when retrofitting a coal fired power plant, MEA can reduce the output of the host plant by 41% while Oxy-fuel reduces the output by 36%.

Converting CO2 streams into chemical streams

Scottish Carbon Capture and Storage has broadened the scope of its research, by incorporating the School of Chemistry at the University of Edinburgh. The School of Chemistry is working on a range of reactions to put our excess CO2 to good use.

Professor Polly L Arnold, Chair of Synthetic Inorganic Chemistry, University of Edinburgh

The groups working on catalyst synthesis at the Joseph Black laboratory. Supervisors are Polly Arnold (far left) and Dr Jason Love (far right).

Carbon dioxide is more reactive and chemically useful than it is often given credit for. In fact, it is already used in industrial processes to make urea, salicylic acid, and some polycarbonate plastics. Globally, about 110 megatons are currently consumed in this way each year.

In nature, nickel-containing enzymes can convert CO2 to carbon monoxide (CO) and water catalytically in ambient conditions. For this to occur, the reaction requires two protons, two electrons and, unfortunately, also a large and complex surrounding protein structure to help control the reaction (which can occur with turnovers of 40,000 reactions per second).

The lab chemist's version of 'two protons and two electrons' is either hydrogen, which is an expensive and high-energy commodity, or water and a lot of electricity. However, given energy and protons, or indeed other high-energy reagents such as epoxides, we can start to design our own catalysts to target not just carbon monoxide, but also a range of other chemicals.

In the Joseph Black laboratory in the University of Edinburgh, we are working a range of reactions that would put CO2 to use. For example, the binding of catalysts to electrodes to reduce the amount of electrical energy required to reduce CO2, and to convert it to other products such as hydrocarbons. We are also working on catalysts that can incorporate the CO2 into new types of polymer. In the context of geological storage, the fundamental chemistry of CO2 binding can be used in the development of leak-sensing electrodes, self-healing cements, and alternative adsorbent design, to name just a few examples.

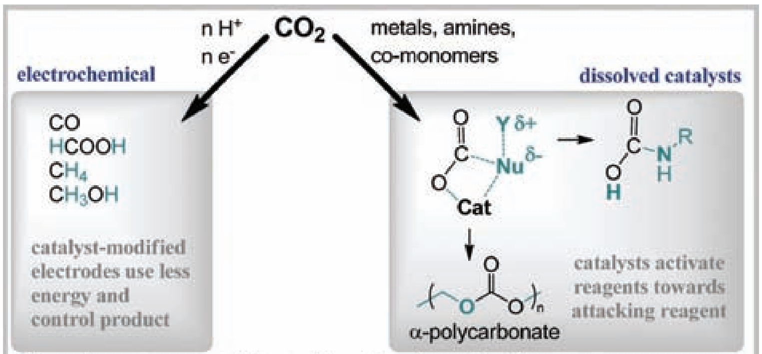
Some major reasons for producing chemicals from CO2 are:

- can replace toxic chemical feedstocks (e.g. phosgene)
- will soon be stored for use in large feedstock reservoirs
- could possibly be used to make totally new materials (e.g. new polymers)
- could provide more efficient and economical routes to existing chemicals

Whatever chemistry we do with CO2, it will make a small impact, and with potentially high product value, and significant positive impact on the global carbon balance.

University of Edinburgh Masters and PhD students, and postdoctoral research scholars are currently working on a range of CO2-related projects, for example:

- Rakesh Barik is studying the electrochemical conversion of CO2 by different catalysts at an electrode, and the coupling of this electrochemistry to renewable energy sources. He is funded by the Carbon Trust, and supervised by Prof Lesley J Yellowlees (Chemistry, UoE) and Dr Dimitri Mignard (Chemical Engineering, UoE)
- Aline Devoille is taking a three month secondment from her PhD studies to investigate the trapping and reduction of CO2 by new supramolecular architectures that combine amines and redox active metals. She is supervised by Dr Jason B Love (Chemistry, UoE).
- Aaron Gamboa is studying the use of asymmetric metal complexes as catalysts, for the copolymerisation of CO2 with other biorenewable monomers, to make highly oxygenated plastics such as polycarbonates. The resulting biodegradable materials will be assessed for their applications to replace traditional plastics in food packaging, elec-



Complementary reactivity studies of carbon dioxide in the Joseph Black Carbon Dioxide Laboratory, University of Edinburgh.

tronic devices, and medical biomaterials. He is funded by Conacyt, Mexico, and supervised by Prof Polly L Arnold (Chemistry, UoE).

- Research Associate Dr. Andrei Gromov is studying the functionalisation of nanostructured carbon materials for small-scale carbon capture from air. He is supervised by Prof Eleanor Campbell (Chemistry, UoE) and Prof Stefano Brandani (Chemical Engineering, UoE).

More information

Scottish Carbon Capture and Storage (SCCS) is the largest carbon storage grouping in the UK, comprising in excess of 65 researchers, at the University of Edinburgh, Heriot-Watt University and the British Geological Survey. Consortium membership includes a wide range of industries and businesses, and helps to sponsor PhD research and MSc training.

SCCS is unique in its connected strength across the full CCS chain and unique in its biochar capability.

www.sccs.org.uk

For further information on the Joseph Black Laboratory please visit: www.homepages.ed.ac.uk/parnold/JoB or contact Ian Sharp: Ian.sharp@ed.ac.uk

Capture news

DOE sponsors research on CO2 conversion

fossil.energy.gov

Research to help find ways of converting into useful products CO2 captured from emissions of power plants and industrial facilities will be conducted by six projects announced by the U.S. Department of Energy (DOE).

The projects are located in North Carolina, New Jersey, Massachusetts, Rhode Island, Georgia, and Quebec, Canada (through collaboration with a company based in Lexington, Ky.) and have a total value of approximately $5.9 million over two-to-three years, with $4.4 million of DOE funding and $1.5 million of non-Federal cost sharing. The work will be managed by the Office of Fossil Energy's National Energy Technology Laboratory.

It is anticipated that large volumes of CO2 will be available as fossil fuel–based power plants and other CO2-emitting industries are equipped with CO2 emissions control technologies to comply with regulatory requirements. While DOE efforts are underway to demonstrate the permanent storage of captured CO2 through geologic sequestration, there is also a potential opportunity to use CO2 as an inexpensive raw material and convert it to beneficial use. The selected projects will develop or improve scalable processes with the potential to use significant amounts of CO2, the DOE said.

CO2 to fuel alliance formed

www.reiinternational.org

An alliance of industry, academic and government organizations has been formed to commercialize technologies that will use concentrated solar energy to convert waste carbon dioxide into diesel fuel.

The alliance team members include Sandia National Laboratories, Renewable Energy Institute International (REII), Pacific Renewable Fuels, Pratt Whitney Rocketdyne (a United Technologies Division), Quanta Services, Desert Research Institute and Clean Energy Systems. In addition, commercial partners have signed on to advance work on the first round of commercial plants.

The project team has received a first phase of funding from the National Energy Technology Laboratory (NETL) to demonstrate these technologies.

The solar reforming technology platform will be colocated next to industrial facilities that have waste CO2 streams such as coal power plants, natural gas processing facilities, ethanol plants, cement production facilities and other stationary sources of CO2.

GoNano Technologies awarded grant for CO2 conversion tech

www.gonano-9.com

The National Science Foundation has awarded a Phase I Small Business Innovative Research (SBIR) grant of $147,095 to GoNano Technologies.

The Moscow, Idaho-based nanotechnology company specialises in the development of high surface area Nanospring materials, and will use the grant to continue developing their Carbon Capture & Recycling (CCR) technology.

Using a photocatalyst consisting of silica Nanosprings coated with a combination of titanium dioxide and proprietary dopants, GoNano Technologies has demonstrated conversion of CO2 to useful and commercially valuable feedstock chemicals, including methanol, formic acid, and formaldehyde. GoNano Technologies says its CCR process is the only photocatalytic carbon recycling system that offers a selectable product output based on input and flow rate.

CO2 Solution announces results of enzyme based capture

www.co2solution.com

CO2 Solution says it has achieved 'significant technical results' towards validating the impact of its enzymatic process on reducing the cost of carbon capture at commercial scale.

CO2 Solution in conjunction with its consultant, Procede Group B.V., has conducted lab scale testing and process modelling which it says has demonstrated the potential to reduce the size of CO2 absorber columns at coal-fired power plants by more than 90% when the enzymatic technology was used with MDEA, as opposed to pure MDEA.

By employing the enzyme, the rate of CO2 absorption in MDEA was increased more than 10 fold, reducing the height of the modelled CO2 absorption column from more than 200 meters to approximately 20 meters. Relatively small quantities of the enzyme catalyst are necessary to achieve the desired rate increase.

Additionally, by taking advantage of the low-energy properties of MDEA, solvent regeneration and process energy consumption is predicted to be reduced by approximately 30% compared to the current industry standard monethanolamine (MEA) process.

These results point to a significant reduction in capital and operating costs of commercial scale carbon capture at typical coal-fired power plants or other large emitters, while using a widely available commercial solvent. The use of the enzyme also holds a distinct advantage in that its use is energy-neutral to the process, as opposed to chemical CO2 absorption promoters, such as piperazine or primary amines, which increase the energy required for subsequent CO2 stripping.

CO2 Solution is developing this technology in collaboration with Codexis. The process is expected to benefit further from low cost carbonic anhydrases developed by Codexis which provide for enhanced stability and catalytic activity in industrial carbon capture solvents at the elevated temperatures typical of commercial operations.

Use of calorimetric techniques for the investigation of CO2 capture and storage

Calorimeters can be used for the investigation of gas-liquid absorption for CO2 capture using frequently used amine solutions and CO2 storage in saline aquifers.

By Pierre LE PARLOUËR, Scientific Director, SETARAM Instrumentation, Caluire, France

Capture and storage demonstration projects are multiplying worldwide as industrial companies are facing the obligation to cut back their CO2 emissions.

As a consequence, industrial interest is generating important technological developments at the process level, but another significant aspect is the drive to find and understand the chemistries and technologies that will provide the most efficient capture and the safest storage in the field.

Most CCS technologies are based upon gas-solid or gas-liquid adsorption or absorption systems and during such a process, heat is exchanged by the system. By measuring this heat, the corresponding thermal data can provide critical information on the amount of adsorbed (absorbed) CO2 at a given temperature and gas pressure and also on the kinetics of the reaction. Such a measurement is ideally performed using the calorimetric technique.

This paper explains how such a calorimetric technique is used for the investigation of gas-liquid absorption for CO2 capture using frequently used amine solutions and for CO2 storage in saline aquifers.

The calorimetric technique

Calorimetry is a common technique used for the measurement of thermodynamic parameters such as enthalpy and heat capacity (1). Though calorimetry is not a new technique, a lot of developments have been made in the last years to make it simpler and more suited to the requirements of the new research projects.

This is typically the case with the growing development of the CCS market and the need to better understand more about the capture and storage processes.

A basic calorimeter is designed to measure any heat change that will occur in a sample undergoing a structural transformation during a process or reaction.

It consists of a measurement chamber surrounded by a detector (thermocouples, resistance wires, thermistors, thermopiles) to integrate the heat flux exchanged by the sample contained within a sample vessel. The measurement chamber is insulated in a surrounding heat sink, made of a high thermal conductivity material.

The heat flux for a given sample at a temperature Ts is equivalent to (figure 1):

$$dqs/dt = - dh/dt + Cs\ dTs/dt \quad (1)$$

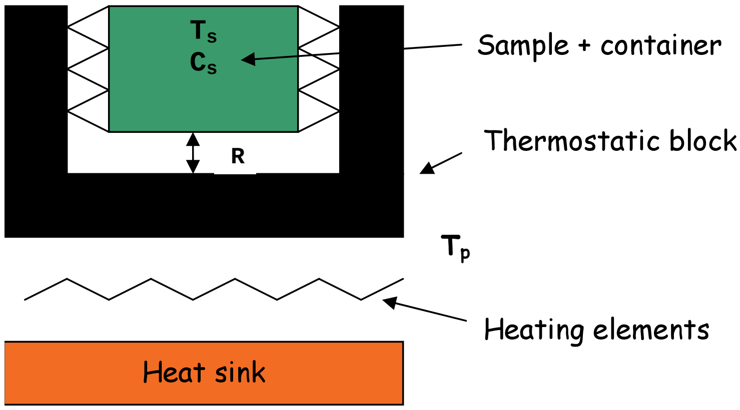


Figure 1: Single cell calorimetric principle

where:

- dh/dt : heat flux produced by the transformation of the sample or the reaction
- Cs : heat capacity of the sample, including the container

The heat flux dqs/dt is exchanged with the thermostatic block at a temperature Tp through a thermal resistance R according to the following relation;

$$dqs/dt = (Tp – Ts) / R \quad (2)$$

From equation (1), it is seen that the thermal contribution due to the heat capacity of the sample and container is significant and will provide a major disturbance at the introduction of the container in the calorimeter. From relation (2), it is also evident that any temperature perturbation of the thermostatic block will affect the calorimetric measurement.

In order to resolve these different problems, a symmetrical calorimeter is preferred. Two identical calorimetric chambers containing a container with the sample and an identical container with an inert reference material are placed in the thermostatic block at the same Tp temperature. The difference of heat flux is measured between the two chambers.

$$dh/dt = - dq/dt + (Cs – Cr)\ dTp/dt – R\ Cs\ d2q/dt2 \quad (3)$$

where:

- Cr : heat capacity of the reference, including the container
- Tr : temperature of the reference

If dh/dt corresponds to an absorbed thermal power due to an endothermic transformation or reaction, the dh/dt value is positive.

If dh/dt corresponds to a released thermal power due to an exothermic transformation or reaction, the dh/dt value is negative.

If the calorimetric test is run isothermally, the parameter dTp/dt is null. In the case of a small perturbation of the temperature Tp of the thermostatic block, the corresponding thermal effect will be minimized if the Cs and Cr heat capacities are similar.

The last term R Cs d2q/dt2 (called also thermal lag) that affects the measurement mostly depends on the thermal resistance or also the time of response of the calorimeter on one side, and the heat capacity of the sample and container on the other side. For long period of time (t>>RCs) it will be negligible.

The Calvet principle

As seen in the previous paragraph, the use of a symmetrical design was a major improvement for the calorimetric technology and was introduced by professors Tian and Calvet (2).

The detection concept is based on a three dimensional fluxmeter sensor. The fluxmeter element consists in a ring of several thermocouples in series (Fig.2). The cor-

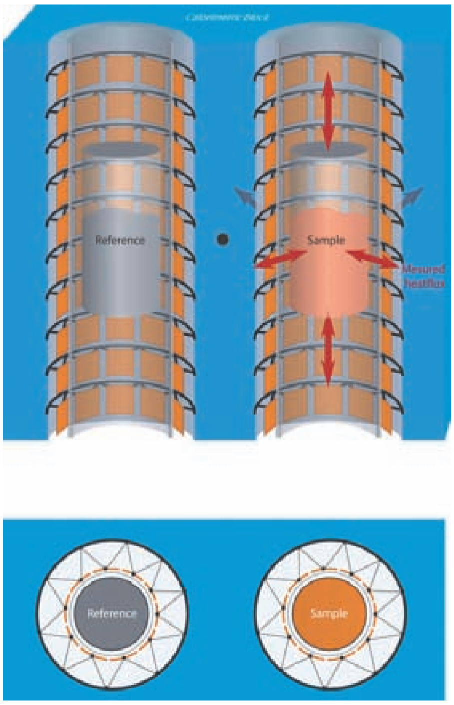


Fig.2: Schematic of the Calvet type calorimeter

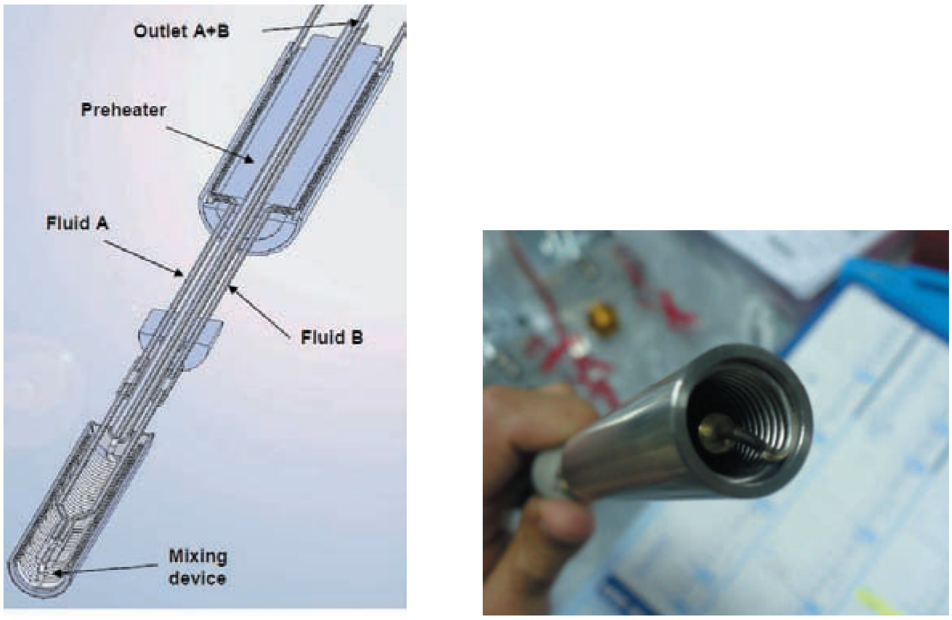


Fig.3: The High Pressure Flow Mixing vessel (cross section and picture)

responding thermopile of high thermal conductivity surrounds the experimental space within the calorimetric block. The radial arrangement of the thermopiles guarantees an almost complete integration of the heat.

The C80 microcalorimeter (the most popular Calvet calorimeter produced by the SETARAM company) is designed with a large experimental volume (15 cm3) that has allowed the design of a large variety of experimental vessels for mixing and reaction investigations (3).

It works according to different calorimetric modes:

- isothermal calorimetry
- scanning calorimetry
- gas adsorption calorimetry
- liquid absorption calorimetry
- mixing calorimetry
- percolation calorimetry
- reaction calorimetry
- pressure calorimetry

This article will focus on liquid adsorption calorimetry as it is the most suitable mode for investigations in the CCS field. In such a mode a liquid is mixed with the solution under study to investigate the corresponding dissolution and absorption under normal or high pressure at a given temperature (4).

In order to work under pressure, a dedicated high pressure mixing vessel was developed to be used on the Setaram C80 calorimeter.

The mixing vessel is made of a stainless steel tube in a helicoidal shape mounted within a cylindrical container. The length of the tube in closed thermal contact with the cylinder is about 240 cm. The fluids A and B are separately introduced at the upper part of the vessel in two vertical and concentrical tubes. The fluids are preheated at the temperature of the calorimetric vessel before entering the calorimetric zone, in order to avoid thermal perturbation due to the variation of heat capacity of the fluids.

Mixing (dissolution, reaction) starts when the thinner part of the tube is reached at the bottom of the calorimetric vessel. The heat that is associated with the reaction is exchanged between the rolled tube and the calorimetric block through the wall of the vessel in an isothermal mode. The resulting mixture is extracted from the vessel through the oulet tube.

The flow mixing vessel operates from room temperature to 200°C and for a range of fluid pressure from 0.1 to 20 MPa. The fluid flowrates vary from 50 to 1500 µl/min, which allows coverage of a wide range of mixture compositions.

In the case of introducing CO2 in a solution, the experimental diagram is shown in figure 4. In a first stage, the solution (in red) is only introduced in the calorimetric vessel at a controlled temperature and flowrate under a given pressure. This flow defines the base line for the calorimetric signal as seen on the curve.

In a second step, CO2 (in blue) at a selected flowrate and pressure is added. This introduction gives rise to an exothermic deviation of the calorimetric signal due to the reaction. After reaching its equilibrium, the flowrate of CO2 is halted and the calorimetric signal returns to the initial baseline.

The integration of the calorimetric signal corresponds to the heat produced by the reaction between the solution and CO2 at a given temperature.

The use of such a calorimetric vessel is illustrated with two applications in the field of CCS:

- calorimetry for CO2 capture on liquid sorbents
- calorimetry for CO2 storage in saline aquifers

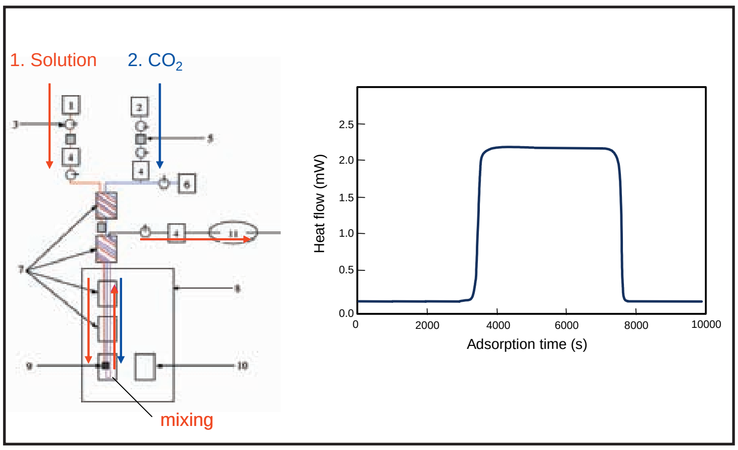


Figure 4: The experimental diagram and the resulting calorimetric curve

Calorimetry for CO2 capture on liquid sorbents

The use of chemical sorbents is one of the most popular absorption technique for the CO2 capture in post combustion processes. In an absorption based capture process, CO2 reacts with a liquid chemical, while in adsorption the CO2 will be attached to the surface of a chemical, also called adsorbent, which in most cases is a solid material (this process can also be investigated with the calorimetric technique but is not described in this article).

CO2 is removed by a chemical absorption process involving the interaction of a flue gas stream with an aqueous amine solution. CO2 reacts with the amines to form a soluble carbonate salt. This reaction is reversible and the CO2 can be released by heating the solution with the carbonate salt in a separate stripping column (Figure 5)

In such an industrial process, the amine solution is introduced at the top of an absorption tower while the exhausted fume containing carbon dioxide is introduced at the bottom. As an intimate contact is reached in the absorption tower, the amine solution chemically absorbs the carbon dioxide from the gaseous stream. Such a gas treating process especially requires two types of thermodynamic parameters:

- CO2 solubility in the amine solution
- enthalpy of absorption between CO2 and the amine solution.

The gas solubility defines the capacity of adsorption of CO2 for a selected amine solution at given experimental conditions (temperature, flowrate, pressure).

The enthalpy of absorption, according to the amount of absorbed gas and the corresponding heat capacities of solutions, define the temperatures of the fluids when they exit the absorption columns.

Many investigations are realized on the capture of carbon dioxide for the reduction of the greenhouse effect. Industrial processes are mostly based on the absorption in aqueous solutions of amines. In particular, the (CO2 + H2O + AMP) system is interesting because of the specificity of the alkanolamine (5). Indeed, the AMP (2-amino-2-methyl-1-propanol) is a hindered primary amine and the carbamate formed with the hydrogen carbonate is unstable.

The calorimetric data can serve for an indirect determination of the saturation loading point of CO2 corresponding to the limit of solubility of CO2 in the aqueous AMP solution. For this purpose the enthalpy –Hs expressed as kJ/mol of AMP is plotted (Figure 6) versus the CO2 loading a. The enthalpy of solution -Hs increases up to the saturation of the AMP solution. For the (CO2 + H2O + AMP) system the enthalpy does not vary linearly with a up to the saturation point.

If the fluid pressure is increased (Figure 6), the CO2 solubility is slightly enhanced.

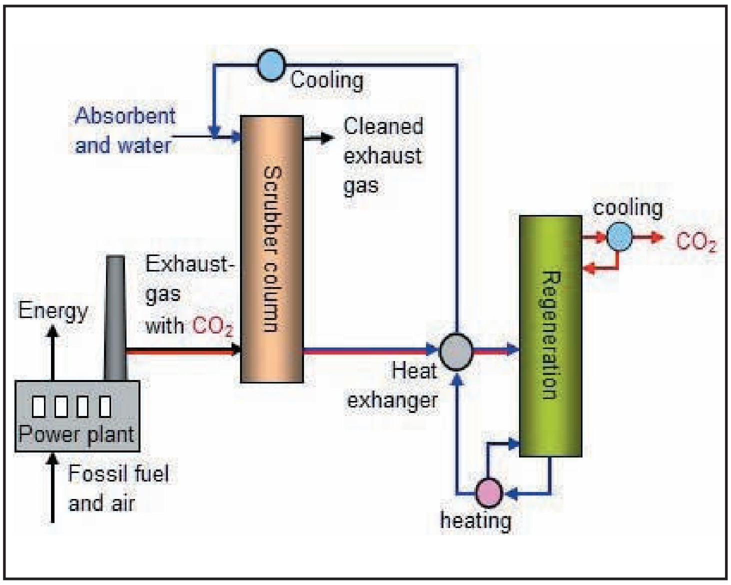


Figure 5: Post combustion process ((from Bellona CCS website)

Calorimetry for CO2 storage in saline aquifers

The emission of greenhouse and acid gases, resulting from the combustion of fossil fuels, or present as constituents of natural gas, must be reduced. One procedure consists in the capture, the transport and finally the geological storage (sequestration) of these gases in depleted oil and gas reservoirs, unminable coal beds or in deep saline aquifers.

As the transfer of acid gases in saline aquifers are performed under high pressure, data on solubility of weak electrolyte gases like carbon dioxide and hydrogen sulphide in geological brines are therefore of direct interest for processes developed, namely by the petroleum industry, for storage of the acid gases. Calorimetry is again the ideal experimental solution for the investigation of the dissolution of CO2 in water and aqueous solution of sodium chloride under supercritical conditions. The calorimetric information on the thermodynamic understanding of the dissolution of CO2 as a function of temperature and pressure will be very helpful for the modelling of gas sequestration in deep saline aquifers.

The high pressure flow mixing vessel, previously described, was used to measure the enthalpies of mixing of CO2 in water at 323.1 K and different pressures from 2 to 20MPa (6)

The enthalpy of solution of carbon dioxide in water is exothermic in this temperature and pressure range and decreases in absolute value with increasing pressure (Figure 7).

At a given pressure, the mixing enthalpy reaches a maximum. The corresponding curve allows the limit of solubility corresponding to a given CO2 concentration to be determined. This limit of solubility increases with pressure.

The calorimetric test can also be used to investigate the effect of salt concentration on the enthalpies of solution.

It is also adapted for experiments with toxic gases (like H2S) at high pressure.

Other calorimetric applications for the CCS research area

This article has only shown two examples of applications of the calorimetric technique in the field of CO2 capture and storage. But more applications can be achieved through this technique, especially when it is combined with a gravimetric or a volumetric technique. Here is a non exhaustive list:

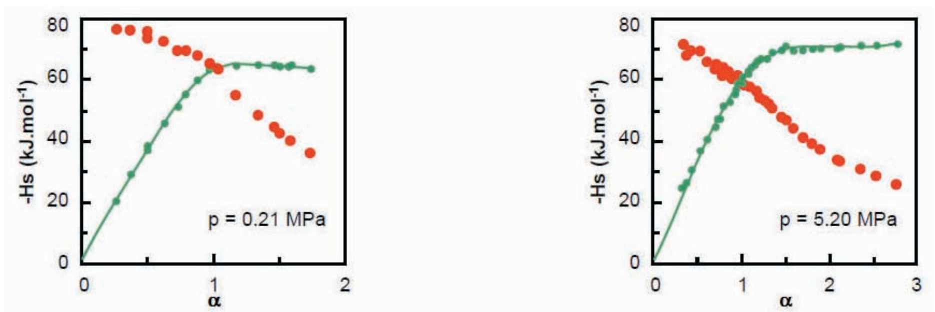


Figure 6: Enthalpy of solution versus CO2 loading for aqueous solution of AMP 15 wt% at 322.5 K:
° enthalpies of solution per mole of gas (-Hs/(kJ/mol of CO2));
° enthalpies of solution per mole of amine (-Hs/(kJ/mol of AMP)).
(from reference 5)

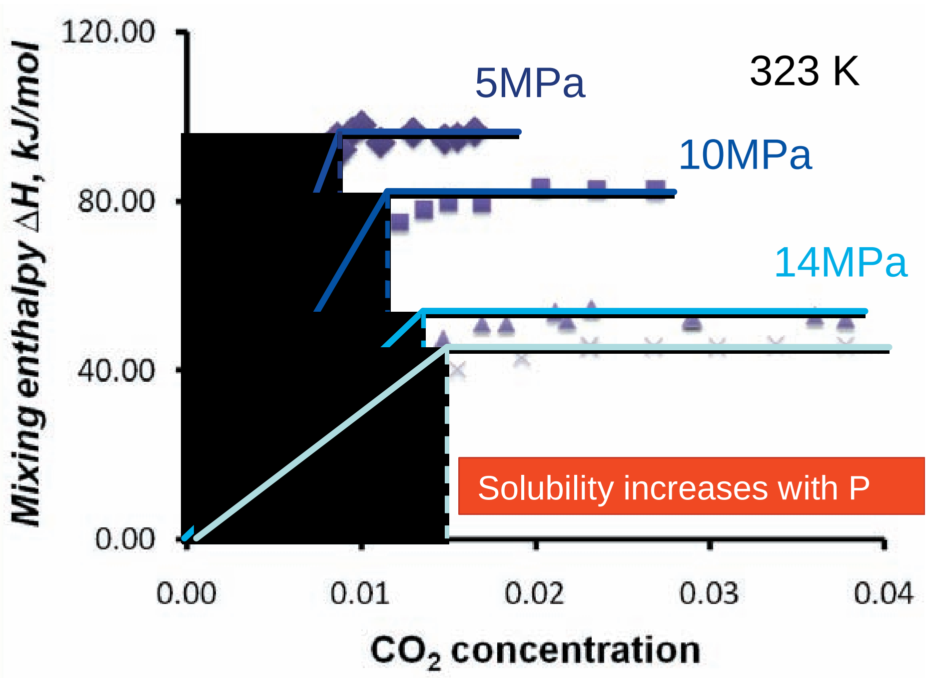


Figure 7: ΔHmix (kJ mol–1 salt free solution) at mNaCl = 1, T = 323.1 K, P = 5, 10, 14 and 20 MPa (from reference 6)

For capture:

- Characterisation of gas separation membrane
- Evaluation of solid adsorbents (activated carbon, zeolites, MOF's)
- Gasification of coal

For storage:

- Characterisation of CO2 (adsorption/desorption) of coal, basalts…
- Investigation under supercritical CO2
- Characterisation of CO2 hydrates

The flexibility and the wide experimental possibilities make the calorimetric technique an ideal and powerful tool for the CCS research area.

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More information

Pierre LE PARLOUËR is the scientific director of Setaram Instrumentation specialized in the design and production of thermal analyzers and calorimeters. He is a member of the French "Club CO2".

www.setaram.com

email: leparlouer@setaram.fr

Transport and storage news

DOE demonstrates viability of CO2 storage with EOR

fossil.energy.gov

A field test conducted by a U.S. Department of Energy (DOE) team of regional partners has demonstrated that simultaneous CO2 storage combined with enhanced oil recovery (EOR) is viable in carbonate reservoirs.

The Plains CO2 Reduction (PCOR) Partnership, one of seven in DOE's Regional Carbon Sequestration Partnership program, collaborated with Eagle Operating Inc. to complete the test in the Northwest McGregor Oil Field in Williams County, N.D.

The test used the 'huff-and-puff' method of enhanced oil recovery which proceeds in three phases: injection (the huff stage), "soaking" for a short period of time, and production (the puff stage). Compared to other huff-and-puff operations, the PCOR Partnership test was unique for several reasons:

- The depth (approximately 8,050 feet), was among the greatest.

- Pressure (3,000 pounds per square inch) and temperature (180 degrees Fahrenheit) were among the highest.

- The formation was a carbonate rather than clastic reservoir.

The test was conducted using a producing oil well in the Mission Canyon Formation, part of the Madison Group of Mississippian-age carbonate rocks in the western United States. During the test, 440 tons of liquid CO2 were injected into the well to a depth at which CO2 is miscible and blends with residual in-place oil. Following 2 weeks of "soaking," the well was placed back into production.

Production more than doubled over the course of a 3-month period, increasing from a baseline rate of 1.5 stock tank barrels (STB) per day to 3-7 STB per day. The percentage of oil in the produced fluid, commonly referred to as the "oil cut," also increased, more than doubling from less than 3 percent to 6 percent.

The test also determined that two Schlumberger technologies, a reservoir saturation tool (RST) and vertical seismic profiling (VSP), may be effective tools for detecting and monitoring small-volume CO2 plumes in deep carbonate reservoirs to ensure safe and permanent sequestration.

CSIRO partners in China for CO2 storage project

www.csiro.au

CSIRO is partnering with China United Coalbed Methane Corporation Limited (CUCBM) on a AUS $10 million CO2 storage with enhanced methane recovery joint demonstration project.

The project will focus on advancing enhanced coal bed methane (ECBM) recovery and providing a pathway to adoption for near zero emissions technology from coal-fired power.

ECBM involves the injection of CO2 into coal seams to displace methane that can be used to generate energy, while providing the additional benefit of reducing greenhouse gas emissions by storing the CO2 underground.

Director of CSIRO's Advanced Coal Technology research, Dr John Carras, says the ECBM project will trial new approaches to maximise CO2 injection and methane recovery.

"ECBM wells are typically drilled vertically to inject CO2 into coal seams but this demonstration project will drill horizontally meaning the entry point of the well is more directly embedded in the coal seam, which we predict will increase the flow rate of CO2 for underground storage," Dr Carras said.

CSIRO's research is supported by the Japan Coal Energy Centre, JCOAL. The project has received funding from the Chinese and Australian Governments as part of the Asia-Pacific Partnership on Clean Development and Climate.

The ECBM demonstration project builds upon CSIRO's existing collaborations with China, which include supporting the launch of a post combustion capture (PCC) pilot plant in Beijing and the first capture of CO2 in China using PCC technology.

Work has also begun on a second, transportable PCC pilot plant that is designed to capture 600 tonnes per annum of CO2. The collection of robust data from this demonstration will inform the techno-economic assessment of PCC and direct the next steps in commercial-scale technology development.

CO2 storage in Scotland Moray Firth - study

www.bgs.ac.uk

The Moray Firth region in Scotland is being examined for the storage of CO2 emissions in a £290k study by a consortium of the Scottish Government and industry.

The Captain Sandstone will be evaluated for its capacity, technical feasibility and commercial viability as a CO2 store by scientists at the Scottish Centre for Carbon Storage (SCCS).

The target rock in the Moray Firth is buried more than half a mile below the sea bed and lies at least 30 miles into the North Sea. It is one of many sandstones filled with salt water that provide more than 95% of potential CO2 storage capacity in the northern North Sea.

New geological mapping and modelling of the Captain Sandstone will appraise the thickness, extent and fluid flow properties of the rock. The study will also address the challenges of CO2 injection and monitoring to assess suitability of this and other North Sea sandstones.

Computer modelling of CO2 injection into the rocks will test the storage site and its long-term performance to ensure CO2 remains permanently locked in.

The research will be completed this year and the results will be available to inform the implementation of carbon storage in Scotland and northern England.

US Geological Survey to reassess nation's CO2 storage potential

www.usgs.gov

A new methodology to assess the US's potential to store CO2 is available and the The U.S. Geological Survey will now begin a national assessment of CO2 storage potential.

The new methodology identifies a means to assess the mass of CO2 that can be retained within the pore space in underground rocks. The process of injecting liquid CO2 into subsurface rocks is known as geologic carbon sequestration.

The USGS methodology builds upon its draft published in March 2009. The original draft report went through extensive external peer review, and this revised version incorporates suggestions from the review committee and other federal agencies.

The processes by which rock formations can trap and seal CO2 were addressed in this updated methodology. The revised approach also estimates the potential storage capacity for the entire storage formation, which includes both saline formations and petroleum reservoirs. This allows for a more comprehensive look at the entire storage formation and accounts for various trapping mechanisms within the formation.

The methodology was developed in accordance with the Energy Independence and Security Act of 2007, which authorized the USGS to develop the methodology and conduct the national assessment. This research also benefited from discussions with a variety of partners and stakeholders, such as the Department of Energy and the National Energy Technology Laboratory, State Geological Surveys, the Environmental Protection Agency, and the Bureau of Land Management.

This assessment methodology for storing carbon dioxide focuses on the "technically accessible resource," which is the geologic resource that may be available and sequestered using present-day geological and engineering knowledge and technology. No economic factors are used in the estimation of the volume of resource.

Preparing a gas sample for carbon isotopic analysis. Isotopic and chemical tracers are used in a comprehensive monitoring and verification program to verify the secure containment of injected carbon dioxide. (Image ©CSIRO)

DOE CO2 tracer technology tested in New Mexico

The SEQURE tracer technology developed by the Office of Fossil Energy's National Energy Technology Laboratory tracks the movement of CO2 in geological reservoirs.

The technology can measure concentrations as small as parts-per-quadrillion and differentiate injected CO2 from natural CO2.

It was successfully tested in a San Juan Basin coalbed site in New Mexico. SEQURE uses perfluorocarbon tracers (PFTs) – non-toxic, chemically inert clear colorless liquids – to provide a verifiable way to measure CO2 movement as well as provide leak detection.

At the San Juan Basin, the SEQURE tracers detected gas first in the eastern-most of three production wells and then in the southwest production well. Numerical models used for the test site had predicted the CO2 movement but indicated that the movement would initially occur at the southwest well.

In 2009, the patent-pending SEQURE technology earned R&D Magazine's prestigious R&D 100 Award.


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