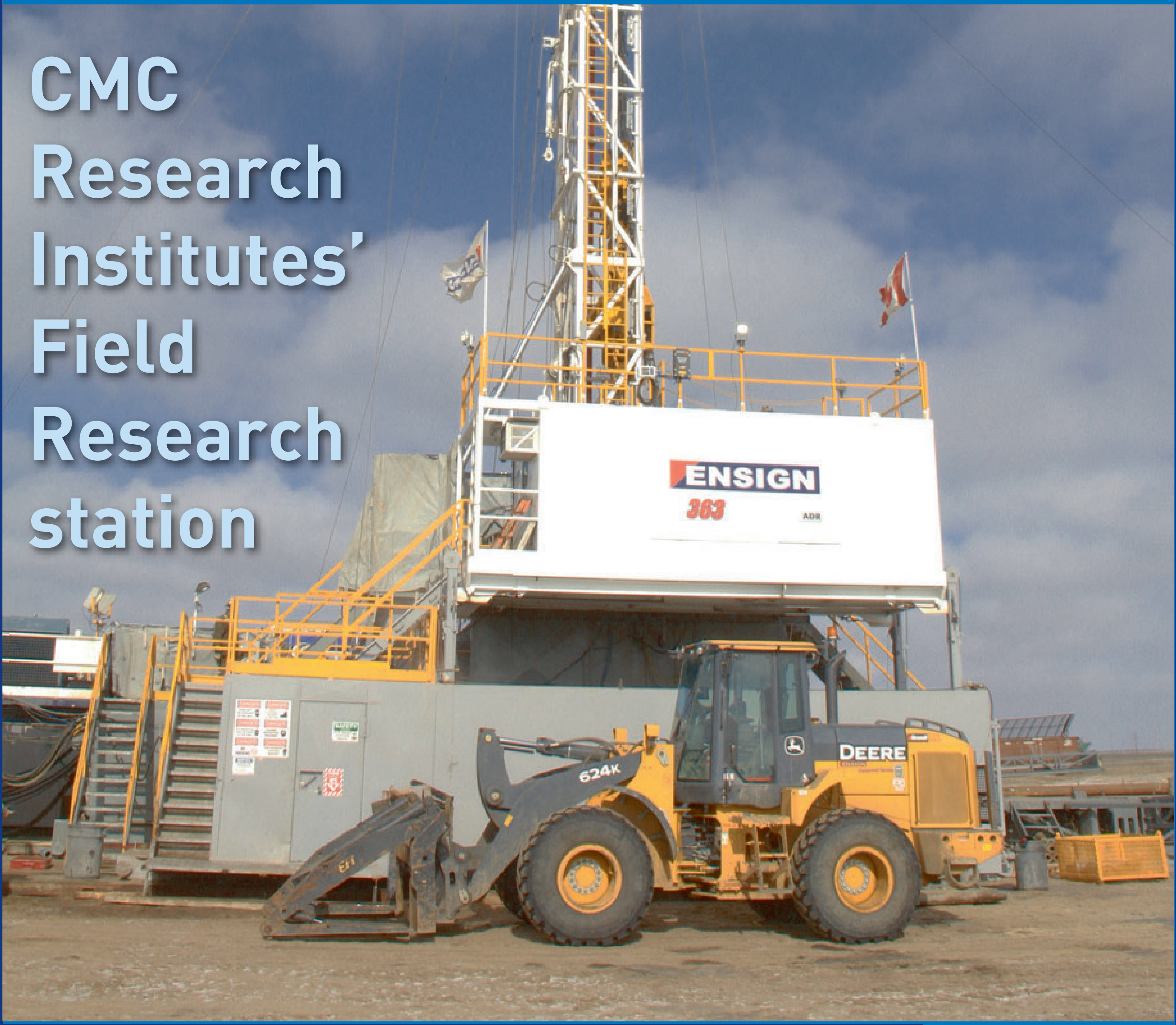
# Carbon Capture Journal

## CCS in Canada

CCUS technology breakthroughs at the University of Regina

Aquistore begins CO2 commissioning

May / June 2015 Issue 45




Alberta keeps its place at the forefront of CCS deployment

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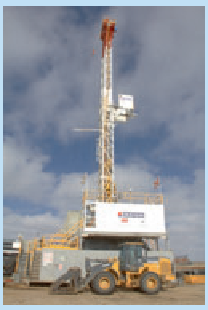

*Front cover: A drilling rig drilling the first well at CMC Research Institutes' Containment and Monitoring Institute (CaMI) Field Research Station.*

*The CaMI station will enable Canadian and international companies, as well as researchers, to test and calibrate all ranges of monitoring technologies.*

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## Leaders - CCS in Canada



## Projects and policy



## Capture and utilisation



## Transport and storage

# Alberta bound - CMC Research Institutes' Field Research station

Canada's first research facility for containment and monitoring of carbon dioxide takes root in the prairies.

By Mark Lowey, Calgary-based journalist and managing editor of EnviroLine

**Canada's first research and technology development facility for monitoring of carbon dioxide and other gases injected into the subsurface is under construction in the province of Alberta. The first well at the new Containment and Monitoring Institute (CaMI) Field Research Station was successfully drilled this spring. Information from this well (rock cores, cuttings and well logs) is being used to fully characterize the properties of the subsurface injection zones and the overlying cap rock.**

The CaMI station is being built by CMC Research Institutes (previously known as Carbon Management Canada), a federally incorporated, not-for-profit company based in Calgary, in collaboration with the University of Calgary. CMC Research Institutes is dedicated to helping technology developers identify opportunities and create solutions for decarbonizing the fossil energy industry. The CaMI station is supported by federal government investment and industry partnership, and will offer an unprecedented opportunity to develop and test new geophysical and geochemical measurement, monitoring and verification technologies.

"This is a very positive step in the advancement of carbon capture and storage (CCS) technology in Canada," says Don Lawton, director of CaMI and a geophysics professor at University of Calgary. "The CaMI Field Research Station will further build on Canada's international reputation for monitoring CO2 injection and storage, particularly with its capability for monitoring and secure containment of gases in the subsurface at intermediate depths."

The CaMI station will enable Canadian and international companies, as well as researchers, to test and calibrate all ranges of monitoring technologies in order to quantify the detection threshold of CO2 for the station's proposed injection depths of 300 metres and 500 metres. "This facility will increase understanding of the outcome of gas migration in the shallow to intermediate depth ranges, which hasn't been done before," Lawton says.

The knowledge acquired will be critical to the CCS industry in ensuring the safe, long-term containment of CO2. Research and development done at the field research station can also be applied in other sectors, such as the steam-driven, in-situ oil sands industry to ensure underground steam chamber containment, the shale gas industry to monitor hydraulic fracturing (including fugitive methane migration and potential methane contamination of groundwater), and in other applications such as subsurface disposal of process water and acid gas.

CMC Research Institutes is investing $4.4 million in the CaMI station. Canada's federal government considers CCS to be a key technology for reducing the nation's greenhouse gas emissions. In February this year, Western Economic Diversification Canada announced a $4.9-million investment in the new research facility. As stated by The Honourable Michelle Rempel, Minister of State for the department, "This world-class field testing site will enhance CO2 storage, helping international climate change efforts and increasing the overall competitiveness of Canada's energy industry." CMC Research Institutes plans to generate at least another $5 million over five years for the station's initial $15-million budget, through fees for industry participation, site access for technology developers and additional government support.

## Industry already collaborating

The CaMI Field Research Station already has attracted direct industry support and collaboration. The station is located about 165 kilometres southeast of Calgary, on a parcel of prairie land owned by Cenovus Energy Inc., a Canadian integrated oil company headquartered in Calgary. Cenovus provided a 10-year lease for surface and subsurface access at the site, as well as the company's regional seismic data in the area.

*Don Lawton, director of CaMI and a geophysics professor at University of Calgary*

Cenovus owns and operates a CO2-enhanced oil recovery project in the adjacent prairie province of Saskatchewan. That project has safely sequestered about 24 million tonnes of CO2, while recovering more oil from an aging oilfield. "Additional research into CO2 containment is an important step towards making this technology more commercially viable and helping our industry reduce greenhouse gas emissions," said Dave Mudie, Senior Vice-President of Conventional Oil and Natural Gas at Cenovus.

Schlumberger Carbon Services also is collaborating, as the CaMI station's project manager, with CMC Research Institutes in designing and constructing infrastructure for the facility, to "help to further demonstrate safe CO2 geological storage in Canada," company president Dwight Peters said. Also, during drilling of the first well at the station in February, SGS Canada – headquartered in the province of Ontario – was onsite testing rig-deployable QEMSCAN® technology, provided by FEI, a microscopy services firm headquartered in Oregon. Using drill cuttings and cores, the QEMSCAN® system micro-analyzes mineral composition and structure of the rock – providing a geological column for the entire well – in near real time. “This is exactly what the field research station is designed for, to scope out and assess new technologies,” Lawton says.

Research and development at the CaMI station will be conducted on a range of new subsurface monitoring, measurement and verification technologies required for Alberta’s CCS industry. The Government of Alberta has committed a total of $1.5 billion over 15 years to build two large-scale commercial CCS projects in the province.

“New business and technologies will be needed not only for regulatory compliance but also for verification of conformance and containment, and crucial performance validation to drive the improvement of processes and to alleviate any public concerns about technical safety,” Lawton says. New technologies could include fibre optic devices, “slim” wells (with reduced borehole diameters), micro-chip ‘laboratories’ and nano-sized sensors, new analytical instruments for air and water analyses, as well as new approaches to integrating various types of geophysical data.

## ‘Cadillac’ well drilled for CO2 injection

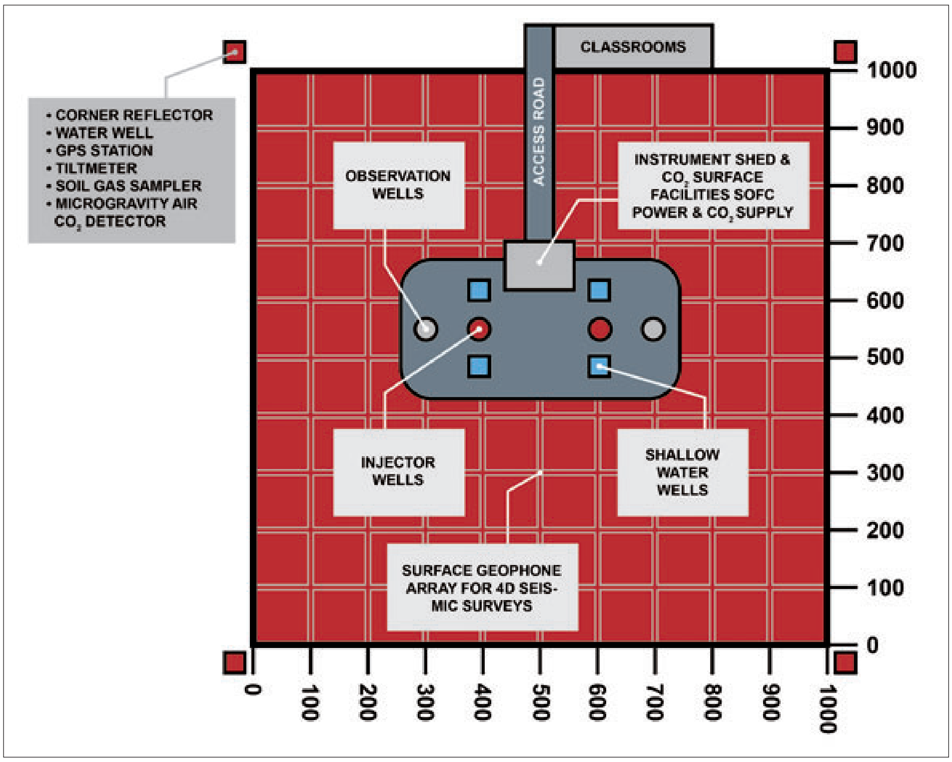
The CaMI Field Research Station is being designed to track and quantify the carbon dioxide plume in the subsurface, and detect any migration of CO2 through the overlying shale cap rock into shallower aquifers or a release into the soil zone or the atmosphere. Current plans call for a total of four wells to be drilled – two for CO2 injection and two observation wells for monitoring. The initial well was drilled 550 metres deep into a sandstone formation.

“It was a ‘Cadillac’ well, because we wanted to complete it to the highest level of integrity,” Lawton says. Since injected CO2 is slightly acidic, acid-resistant chrome steel, rather than conventional mild steel, was used for the well casing, along with a special CO2-resistant cement to anchor and seal the casing. Researchers will be able to compare corrosion rates in the ‘Cadillac’ well with those in an observation well that will use conventional steel and cement.

*Trucks doing seismic work at Field Research Station site in 2014*

Pending approval from the Alberta Energy Regulator, the first completed well will inject CO2 into an intermediate-zone formation at a depth of 500 metres, while a second well still to be drilled will inject CO2 into a shallower zone at 300 metres. Although the first well could also be used for shallow-zone injection, having two separate injection wells will make it much more efficient for researchers to inject and monitor the two distinct CO2 plumes, Lawton explains.

Two nearby observation wells, one 500 metres deep and the other 300 metres deep, also will be drilled. Both observation wells will be instrumented all the way from surface to the base of the well. Lawton says it’s crucial to develop new CO2-detection and monitoring technologies in the shallow-to-intermediate subsurface, because that’s where any CO2 migrating from deeper zones through, for example, an old well bore or geological fault, needs to be detected. “If there was a pathway that




*Map of infrastructure at the Field Research Station* connected a deeper injection zone to this intermediate zone, that's where we need to be undertaking monitoring so we can immediately remediate the program to minimize gas migration to the ground surface."

At least three groundwater monitoring wells also will be drilled onsite. Near-surface hydrological studies will be done to better understand shallow groundwater systems and fluid flow prior to the injection of any CO2. This is standard best-practice in order to monitor shallow groundwater during the injection programs.

## First CO2 injection planned for early 2016

Pending regulatory approval, researchers plan to inject the first carbon dioxide at the CaMI Field Research Station in early 2016. The station is designed to inject relatively small amounts of up to 1,000 tonnes of CO2 per year into the subsurface. In comparison, Shell Canada's Quest commercial CCS project will inject more than 1 million tonnes of CO2 per year from the company's Scotford oil sands upgrader near Edmonton, at a depth of 2,300 metres.

"However, the goal at the CaMI station is not CO2 storage capacity, but rather we want to be able to detect as little CO2 as possible," Lawton notes. Alberta's other current commercial CCS project is the Alberta Carbon Trunk Line, an endeavor being led by Enhance Energy Inc.

CaMI researchers will spend this summer analyzing cores and well logs from the first injection well and running numerical simulations to design the optimum CO2-injection volume, as well as the best drilling locations for the remaining three wells. "The reservoirs that we want to inject into look really good on the log data from the initial well," Lawton says.

Carbon dioxide for the facility will initially be obtained from industrial sources and trucked to the site. However, the funding provided by Western Economic Diversification will enable researchers to purchase a novel solid oxide fuel cell that will produce CO2 along with clean heat and power for onsite operations. It is scheduled to be deployed by late 2016 or early 2017.

During drilling of the first injection well, a research team led by Bernhard Mayer, a professor of geochemistry and head of the University of Calgary's applied geochemistry group, launched an extensive geochemical sampling and monitoring program onsite. The team used online analyzers to measure, in recirculated drilling fluid, the CO2 and methane concentrations and carbon isotope ratios of CO2 and CH4 every five metres as drilling progressed to the 550-metre depth.

"This work was to establish gas occurrences and the isotopic fingerprints throughout the entire well," from the shallow groundwater zone to the intermediate zone to the deepest injection zone, Mayer says. Having this "library" of chemical and isotopic fingerprints for each formation will enable researchers, in the event of gas migration, to make an "educated guess" about which formation the breach is coming from.

Funding provided by Western Economic Diversification allowed CaMI researchers to purchase a $700,000 mobile geochemistry laboratory to be deployed this summer. This unit will have state-of-the-art laser-based carbon isotope analyzers for CO2 and methane, along with two new gas chromatographs – one for soil gases and another for analyzing produced gases – plus a separate analyzer for hydrogen sulphide gas. Another chromatograph for liquids will be used for water chemistry analysis in the field.

"The mobile unit will be important for accurate containment and leakage monitoring in CCS operations with results being available immediately at the field site," Mayer says. "It also can play an important role in well leak investigations, including shale gas and oil sands wells, through detecting gas composition and isotopic fingerprinting."

CaMI will partner with the University of Calgary and others to develop training programs at the facility for graduate and undergraduate students, as well as commercial training for industry. "The CaMI Field Research Station will facilitate significant research and training opportunities for our scholars and students," says Ed McCauley, Vice-President (Research) at the university. CMC Research Institutes also is inviting partners to help develop the field research station through membership, sponsorship, contract R&D arrangements and other collaborative mechanisms.

"We've received a lot of interest from international researchers," says Lawton, who will be travelling to the United Kingdom to meet with several CCS researchers there. CMC Research Institutes has a memorandum of understanding with the UKCCS Research Centre to foster collaborative research. Also, researchers with the U.S. Department of Energy at Lawrence Berkeley National Laboratory plan to test new monitoring technologies at the CaMI field research station.

*Bernhard Mayer, a professor of geochemistry and head of the University of Calgary's applied geochemistry group*

Research centres in Norway, South Korea, Scotland and Australia also have expressed interest in working at the site. "We're open for business," says Richard Adamson, managing director of CMC Research Institutes. "And we are excited about working with these groups to advance the solutions for the measurement and monitoring of stored carbon dioxide and other gases underground."

## More information

For more information about the CaMI Field Research Station, contact Don Lawton at +1 403-210-6671 or email: **don.lawton@cmcghg.com**

**www.cmc-nce.ca**

# Aquistore begins CO2 commissioning

**The Petroleum Technology Research Centre in Regina is advancing three projects looking at CO2 storage and enhanced oil recovery.**

By Aleana Young, Communications and Project Officer, Petroleum Technology Research Centre

**The Petroleum Technology Research Centre (PTRC) is an internationally recognized not-for-profit based in Regina, Saskatchewan. With twin-focuses on carbon dioxide storage and utilization, and enhanced oil recovery of unconventional oil resources such as heavy and tight oil, PTRC manages and funds research projects – both applied and field – focused on increasing production from existing reserves while reducing environmental impacts.**

PTRC manages consortia projects, such as the IEAGHG Weyburn Midale CO2 Monitoring and Storage Project. These leading projects bring together industry and government to fund research critical to both. Currently, PTRC has three large projects underway: Aquistore, SaskCO2USER, and HORNET.

*Well logging at the Aquistore project*

## AQUISTORE

CO2 commissioning has begun at Aquistore, Canada's first deep saline storage project.

Aquistore is the CO2 storage and independent research project associated with SaskPower's Boundary Dam Integrated Carbon Capture and Storage (CCS) Demonstration Project. As part of the world's first commercial scale CCS project associated with a coal-fired power plant, Aquistore puts the 'S' in CCS.

Located outside of the town of Estevan, Saskatchewan, Aquistore is on SaskPower land, approximately 2.8 km from its source – the 160 MW Unit 3 of the Boundary Dam Power Station. Aquistore is composed of two wells – one injection and one observation – and a multitude of monitoring equipment, both tried and true and additional pilot or experimental techniques.

The two Aquistore wells are the two deepest ever drilled in the province of Saskatchewan. The injection well reaches 3396 m total vertical depth (TVD), while the observation well located 150 m to the north, reaches a TVD of 3400 m. Aquistore's targeted formation is the Deadwood formation – a regionally extensive sandstone that contains intervals of silty-to-shaley interbeds.

The overlying formation is the Winnipeg which is comprised of a lower sandstone (the Black Island member) and an upper shale which forms the primary seal to the storage complex (the Icebox member). The Deadwood and Winnipeg formations are the deepest sedimentary units in the Williston Basin, and are below all oil production and potash-bearing formations in the region. The geological formations selected for Aquistore have, in fact, much greater capacity for storing CO2 than oil reservoirs in western Canada.

Aquistore is integrated into full chain CCS. While Aquistore itself is a dedicated CO2 storage project, the complete project into which it is integrated - the Boundary Dam Integrated CCS Demonstration Project – includes capture, transportation, and CO2 - EOR.

The 3.4 km deep wells are equipped with a number of down-hole monitoring tools and techniques which allow researchers and scientists glimpses of the downhole behavior of the rocks, CO2, and subsurface environment. During the drilling of the wells in 2012, equipment such as the fibre-optic and state-of-the-art digital acoustic sensor lines were strapped to the outside of the well as it was sent into the subsurface.

Each well is also equipped with a number of pressure and temperature gauges and sensors which track the environment of the reservoir and provide a constant stream of information to data collectors at surface.

For monitoring purposes, Aquistore has deployed tried and tested techniques across its area of investigation. However, in addition to these required monitoring tools Aquistore is piloting and testing a number of innovative technologies.

## Fluid Recovery System

A patent-pending Fluid Recovery System is among these techniques. This FRS is a downhole device which was designed specially by experts at the University of Alberta for deployment at Aquistore. Installed in 2013, the FRS allows for reservoir fluids to be sampled and brought to surface while 'in-situ' conditions are maintained. This integrated down-hole fluid recovery system is casing-conveyed. This is accomplished by wrapping and attaching tools to and around the main casing during the drilling of the observation well.

The observation well at Aquistore is equipped with extensive monitoring technology and is instrumented with downhole pressure and temperature sensors, distributed temperature and acoustic sensor lines, and the fluid recovery system this well. The pressure gauges and FRS were housed in steel and pre-welded to multiple outside sections of casing which were specifically designed to be protected from mechanical interference or damage during installation. The FRS housing was installed on the outside of the observation well casing, at reservoir level at the depth of 3227 m.

On surface, the project has a small insulated building mounted on skids which is located next to the observation well. This small building houses the FRS surface control panel and sampling output.

The ability to sample reservoir fluids before, during and after CO2 injection is a critical monitoring technique. The FRS system allows an effective method of documenting the evolution of fluid composition throughout the course of CO2 injection. At Aquistore, the fluid sampling is being combined with mineralogical studies, reservoir modelling work, and geophysical monitoring results. The integration of these methods will contribute to an analysis of geochemical, isotopic composition and/or dissolved gases.

The acquisition of fluid samples under pressure will be applied with a broad range of chemical and isotopic parameters among sampled fluids. These fluids will then be compared to those taken under ambient conditions to help better understand reservoir conditions and assist in assessing depressurization effects on the composition of fluids.

Since installation, several baselines have been sampled and the FRS technology appears to be an innovative and effective method for monitoring reservoir geochemistry.

*Casing conveyed equipment being installed during the drilling of the Aquistore well*

## Aquistore Continued

Aquistore has numerous other monitoring techniques deployed. The project has a strong seismic program including a unique permanent areal array, fibre optic casing-conveyed sensor lines, and a constant seismic source – designed, funded and installed by Japan's Oil, Gas and Metals National Corporation (JOGMEC) and NTT Data.

In addition to the myriad of technical installations and scientific works underway at Aquistore, the project is also working hard to ensure it has a leading public outreach and engagement project. In addition to ongoing communication with local farmers and meetings with city officials and stakeholders, Aquistore has held two public open houses to update the broader community about the project and research.

The most recent open house was held in the fall of 2014. This event provided up-to-date baseline data to the community including groundwater, soil gas and other assurance monitoring results.

Both 'traditional' (paper, printed) materials and electronic and digital tools are used to address questions and hot-button issues such as micro-seismicity. Later this summer, a stakeholder tour will be held on site for interested parties and local authorities keen to explore Canada's first deep saline storage project.

## SaskCO2USER

The Saskatchewan CO2 Oilfield Use for Storage and EOR Research (SaskCO2USER ) project has built upon the rich datasets that emerged from the Weyburn-Midale project. Between the Weyburn and Midale oilfields, Saskatchewan is home to the largest amount of injected anthropogenic CO2 in the world. Over 25 million tonnes of CO2 (as of 2014) are stored, with an additional 2.8 million tonnes expected in 2015.

SaskCO2USER is built on the lessons learned at Weyburn and summarized in the Best Practice Manual and through further development and deployment of research tools, technologies and methodologies in Saskatchewan's CO2-EOR fields and those across the globe. PTRC's SaskCO2USER project will advance both data and applied research for commercial application in high priority areas for CO2-EOR operators and regulators. Special attention will be paid to future and potential recognition of CO2- used in EOR for geological storage credit.

Researchers are spread across North America and Europe, which provides an international context to the findings and commercialized applications. Research areas were identified by industry operators and government regulators. Areas of under investigation include:

• Corrosion and Failure Assessment for CO2 -EOR and Storage

• Minimum Dataset Requirements and Development of a Modelling Workflow for CO2 Migration during Post-EOR Storage

• Monitoring of CO2-EOR Sites for Storage Integrity

• Passive Seismic

• Core Assessment

• Stochastic inversion of Time Lapse Seismic Coupled with Flow Simulations for Reservoir Porosity-Permeability

• Construction and Abandonment Design for Lifecycle Wellbore Integrity

With a focus on commercialization, SaskCO2USER will address CO2 conformance, wellbore integrity, and monitoring. PTRC's SaskCO2USER project will advance both data and applied research for commercial application in high priority areas for CO2-EOR operators and regulators.

Special attention will be paid to future and potential recognition of CO2- used in EOR for geological storage credit. With an end date of September 2015, results and findings will be made available in select public reports, conference presentations, and publications.

## HORNET

In addition to Aquistore and SaskCO2USER, PTRC has a Heavy Oil Research Network (HORNET) which is funded by industry and public sources. HORNET conducts research into enhanced oil recovery, in particular from Western Canada's difficult to access heavy oil deposits, and PTRC's 17 years of enhanced oil recovery research now offers many reports and research findings online.

The HORNET program is guided by technical advisors from funding companies who assist in the design of the research projects, which are targeted at addressing challenges the industry faces in the field. Many of these projects include a focus on or work in conjunction with CO2-EOR.

PTRC has entered 2015 with vigor and is building its project and technical capabilities in both CO2 and hydrocarbon research.

As Aquistore begins CO2 injection and projects such as HORNET and SaskCO2USER continue, PTRC will strive to provide valuable research, forge partnerships, and focus on funding and leading world-class research in EOR and CO2 storage.

### More information

Based in Regina Saskatchewan Canada, PTRC is a not-for-profit corporation whose primary focus is on research of sustainable development technologies for the petroleum industry.

The PTRC is a world leader in the study of the geological storage of carbon dioxide through management of the IEAGHG Weyburn-Midale CO2 Monitoring and Storage Project and the Aquistore Project.

**www.ptrc.ca**

# Alberta keeps its place at the forefront of CCS deployment

Alberta has committed C$1.3 billion to fund two major projects: the Alberta Carbon Trunk Line will be constructed over the next year, while the Quest project is due to be launched later in 2015.

**Alberta, with vast reserves of bitumen in its oil sands, needs to prove itself as a responsible energy producer – from reclaiming mined lands to reducing greenhouse gas emissions. As a leader in the energy business, Alberta saw the necessity to lead on the environmental front. The province's carbon capture and storage program was conceived at this crossroads, and from there, Alberta has come to be recognized as a global leader in advancing commercial-scale CCS projects.**

*Aerial view of Shell Scotford located 40 kilometres northeast of Edmonton, Alberta, Canada. Shell Scotford includes both a refinery, chemicals plant and oil sands upgrading facilities capable of producing 255,000 barrels per day of synthetic crude. Quest will capture and store more than one million tonnes of CO2 per year from the Scotford Upgrader beginning in 2015 – which represents up to 35% of the direct emissions from the Upgrader (Image ©Shell)*

In 2007, Alberta became the first jurisdiction in North America to require large industry – including oil sands upgraders and refineries – to curb greenhouse gas emissions and meet specific reduction targets. Companies that do not reach their targets must pay a per tonne carbon levy or purchase offsets. With these efforts, more than 51 million tonnes of greenhouse gases have been reduced from business as usual since the rules were put in place.

The province's 2008 Climate Change Strategy set out a path for further reductions through to 2050. The document signaled government's intention to begin working on CCS, and in 2009, the Alberta government introduced legislation and funding to encourage early adoption of the technology in the province. Alberta has committed C$1.3 billion to fund two large-scale CCS projects over 15 years. This funding is meant to spur adoption of the technology. The first government-funded project will begin injecting CO2 later this year, and by 2017, when both projects are fully operational, they are expected to reduce emissions by a total of 2.76 million tonnes per year.

Enhance Energy's Alberta Carbon Trunk Line will take CO2 from the Agrium Redwater fertilizer plant and the North West Redwater Partnership refinery for use in enhanced oil recovery – the first oil sands upgrader in the world to have built-in carbon capture capabilities. The majority of the construction on the project is expected to take place over the next year. Both capture points are located in an industrial cluster, which motivated Enhance to build a pipeline with a 14 million tonne capacity, which will provide nearby industries with the ability to easily link to the Trunk Line should they choose to pursue CCS in the future. The project is on schedule to begin commercial operation in 2017.

The Quest project, a collaboration between Shell Canada Ltd., Chevron Canada Limited and Marathon Oil Canada Corporation, will take CO2 from Shell's Scotford Upgrader just outside the capital city of Edmonton, and transport it to a sequestration site for permanent underground storage. Construction is now complete on the project and Shell has started testing the systems in preparation for a full-scale launch in the fall of 2015. Once operational, the Quest project will store approximately one million tonnes of CO2 per year.

The bulk of Alberta's funding for CCS has gone to the projects in the construction phase. Once operational, the projects will receive a per tonne amount based on the actual amount of CO2 stored. As the companies ramped up construction and started their baseline environmental monitoring, the Government of Alberta worked to ensure its policy environment supported the long-term success of CCS in the province.

## Policy Work

To support the projects, Alberta put its regulatory system under the microscope, looking at existing oil and gas rules that would pertain to CCS, as well as best practices globally. The process included over 100 experts from around the world. The Regulatory Framework Assessment report (August 2013) includes 71 recommendations and conclusions on how to enable CCS in the province. This includes clearly defining the roles and responsibilities of the agencies that regulate CCS in Alberta and clarifying approval requirements. Going forward, the recommendations will inform the Alberta government's ongoing work with carbon capture regulation.

When Alberta established its CCS program, government took a bold step in deciding to assume long-term liability for the storage sites. This decision was based on the indefinite length of time that the CO2would be stored, and the assumption that the government is a permanent entity while companies that undertake CCS activities may not be. Liability for storage sites will be transferred only after the government is satisfied that the site has met all closure requirements, a suitable closure period has passed, and the operator can prove that the CO2 is acting predictably within the storage formation.

A Post-Closure Stewardship Fund has been set up to help the Alberta government cover the costs of long-term monitoring and maintenance, as well as any costs related to unforeseen events at the storage site. Companies undertaking long-term CO2 sequestration will pay a project-specific amount for each tonne of CO2stored. To determine the contribution rates, the government set up a working group to establish a methodology to set the rates fairly and consistently. The final methodology formula looks at the potential costs of future monitoring, measurement and verification activities, as well as the costs associated with potential loss of containment from the storage site.

## Knowledge Sharing

A fundamental part of Alberta's CCS program is to advance the technology worldwide through knowledge sharing. The Alberta government is using two approaches – its formal knowledge sharing program for the funded projects and its ongoing outreach and engagement with other countries and organizations working on CCS.

When the funding program was initiated, companies submitting project proposals knew up front that they would be expected to publicly share what they had learned in the course of the project. Lessons learned and technical information were put on a website in 2013. The intention behind this was to help CCS projects from around the world benefit from the knowledge and expertise being developed as a result of Alberta's CCS program. The specialized technical knowledge gained through capturing carbon on bitumen upgraders is expected to drive down the cost of future technologies. This in turn will drive down the costs of reducing carbon emissions from the oil sands.

Alberta's CCS projects have also caught the attention of other governments looking to learn more about CCS. The United States' federal government recently announced a partnership with Shell to develop new technologies for monitoring CO2 stored underground. This work highlights the collaborative nature of Alberta's CCS development program.

Staff from the Alberta government also meet with their counterparts in other jurisdictions to share information and the lessons learned from Alberta's regulatory and project development process. Staying active in the CCS community will help ensure that others learn from Alberta's investment and the province stays in the loop on technical and regulatory innovations taking place in other jurisdictions.

## Innovation

In addition to the government-funded projects, there are many organizations involved in CCS in Alberta. Each of the entities have a slightly different focus on supporting and developing innovation, and have their own role in the province's CCS system.

The Climate Change and Emissions Management Corporation (CCEMC) uses the carbon levy collected from large emitters to fund projects that reduce greenhouse gas emissions. CCEMC funds eight projects that focus on innovations in capture testing and technologies.

Alberta Innovates is a family of research and innovation corporations that interacts with government, industry and academia to develop solutions to global challenges. The corporations work closely with the Government of Alberta to align strategies and priorities. Two of these corporations, Alberta Innovates – Technology Futures and Alberta Innovates – Energy and Environment Solutions, directly support research and innovation in CCS.

Alberta's post-secondary institutions are also involved with CCS. Carbon Management Canada and the University of Calgary, each with a number of CCS focused research efforts, have teamed up to develop a field research station for containment and monitoring technologies.

As well, the University of Alberta has forged a number of collaborative efforts. This includes the Helmholtz-Alberta Initiative, which is looking at CO2-separation and gas purification, and carbon storage. The University of

*The Shell Scotford Upgrader – Quest will add new carbon capture facilities to the three Scotford Upgrader hydrogen manufacturing units (Image ©Shell)*

Alberta is also working with the Canadian Centre for Clean Coal/Carbon and Mineral Processing Technologies on clean coal technologies and CO2 storage.

## Moving Forward

2015 is a big year for CCS in the province. The Quest project will begin commercial operations this fall, and Alberta will begin to see further emissions reductions from oil sands upgrading. Additionally, Alberta is also working to update its climate change framework, which will set the stage for how Alberta will continue to take action on emissions.

Alberta knows that the world is watching. With successful implementation of CCS, Alberta is confirming that it takes environmental stewardship seriously. Additionally, Alberta knows that it has a contribution to make to the world CCS community, and will continue to innovate and share what is learned in the province.

### More information

Alberta Energy: **www.energy.alberta.ca**

Climate Change & Emissions Management Corporation: **www.ccemc.ca**

Alberta Innovates – Technology Futures: **www.albertatechfutures.ca**

Alberta Innovates – Energy and Environment Solutions: **www.ai-ees.ca**

# CCUS technology breakthroughs at the University of Regina

The University of Regina is developing a number of carbon capture technologies, including a low energy solid catalyst amine CO2 capture process, and also working on policy and identifying barriers to public acceptance of CCUS.

**The energy sector is a critical economic driver in Canada, employing a large number of people. Canada also benefits from crude oil royalties, taxes, and sales of petroleum leases. Canada has a high energy use rate per capita, however, with the majority of current energy needs met by combustion of fossil fuels. In addition, the extraction methods are energy-intensive.**

As a result, the energy sector is the key contributor of carbon dioxide ($CO_2$) and other major greenhouse gases (GHGs), which contribute to global warming and climate change issues. The International Energy Agency (IEA) predicts that carbon dioxide capture, utilization and storage (CCUS) will be responsible for 20 per cent of global GHG emissions mitigation by mid-century. Many industry leaders foresee the emergence of a CCUS market as an entirely new industry which is projected to rival the natural gas industry in size.

## Challenges

**Economic:** Since the energy sector is so intricately intertwined with the economy, one of the most immediate challenges is how different countries, including Canada, can use and benefit from fossil fuel resources in an environmentally sustainable manner. In the immediate future, countries such as Canada may be challenged to position themselves as world leaders with the technology and expertise to exploit the new CCUS market. Added to this in the Canadian context, is the challenge of how Saskatchewan can emerge as the key leader, global supplier and trainer of highly-qualified personnel (HQP) in CCUS who will manage the industry.

**Technological:** Until very recently, and in spite of all the robust research and development activities around the globe, critics of any CCUS strategy were of the opinion that Carbon Capture is an "unproven technology". However, as of September 2014, with the start of commercial operations at the Boundary Dam Integrated CCS Demonstration (Saskatchewan, Canada), and the start of construction of the Petra Nova post combustion carbon capture (PCCC)-based CCUS project (Texas, US), there is unequivocal evidence that carbon capture technology does work; thus, such statement no longer carries validity.

There is, however, still the question regarding cost competitiveness of other acceptable energy forms. Although cost that is competitive with other clean forms of energy has been nearly achieved in special cases, but on its own, the absolute cost of coal-based electrical utility fitted with a post combustion-based CCUS unit, or any other CCUS unit, is currently one of the most challenging issues. The cost issue in this case is almost a direct translation of a technology issue. Therefore, the question to ask is: can we develop a technology that can drastically bring down the cost of $CO_2$ capture?

**Social:** On the social side, major issues usually encountered are based on some commonly used terms as "health, safety and environment" and "dirty coal". In the case of the first term, it appears that people are not convinced that CCUS, which is proposed to actually help the environment, will be safe and free from introducing health concerns. The second term appears to stem from the outright reluctance to accept what some people regard as "dirty coal" as a source of energy. Also in play is the reluctance to accept any potential increase in the cost of electricity that may or may not arise from the application of CCUS technology to electrical power plants.

## The opportunity

Many years ago, the University of Regina decided to turn the research, development and demonstration (R&DD) of one of its key strengths, "Carbon Capture, Utilization and Storage (CCUS)" into world-leading capabilities. This has enabled the University to compete with the best in the world for talent, partnership opportunities, and to make breakthrough discoveries. It is with this strategy that the University of Regina can seize emerging opportunities, strategically advance this strength on the global stage, and implement large-scale, transformational and forward-thinking technological R&DD.

## Seizing the Moment

As a result of this transformational and forward-thinking strategy, the University of Regina is leading the way to a sustainable future. Award-winning researchers like Dr. Raphael Idem and his colleagues are developing and testing new methods to capture and manage carbon dioxide emissions from industrial plants.

The technology can be used to make capture plants more efficient and, in turn, economical for industry and consumers, thereby addressing cost and technological issues. It is also work that can reduce industry's impact on the environment and serve as a tool for nations to meet climate change commitments. Through collaboration with industry at home and abroad these researchers are developing practical solutions to the aforementioned global challenges. The following examples capture the essence of these achievements.

## Examples

This specific example consists of a breakthrough and game-changing catalyst-aided amine-based post-combustion $CO_2$ capture technology developed by University of Regina researchers, which uses a solid alkaline catalyst to replace the typical packing internals in the absorber, and a solid acid catalyst to replace the typical packing internals in the desorber.

As a result of catalysis, the external energy requirement (heat duty) for amine solvent regeneration is drastically reduced, approaching the theoretical limit, thereby resulting in drastically reduced operating costs. As well, the kinetics of both absorption and desorption of CO2 is significantly faster due to catalysis thereby resulting in smaller vessel and equipment sizes and the consequent lowering of capital costs.

In addition, with catalysis, it is now possible to use hot water instead of steam for solvent regeneration, where applicable. With this technology, it is also possible to make a strong business case for CCUS rather than depend on policy alone. This is the first time that heterogeneous catalysis technology has been introduced to CO2 capture.

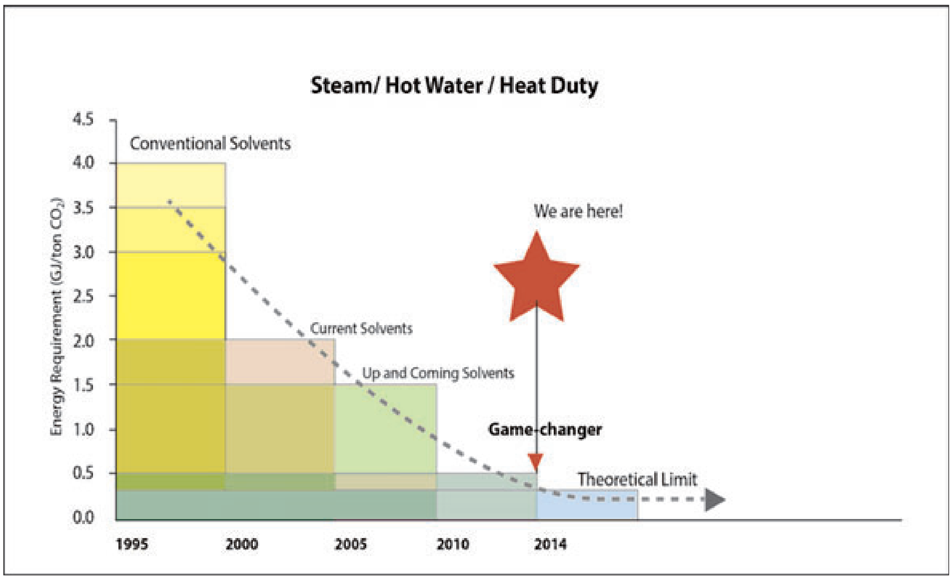
This technology is applicable to the capture of CO2 not only from electric power utilities, both also from other large point sources of GHG emissions such as natural gas processing, petroleum refining, oil sands operation, biogas production, cement manufacturing, etc.

Another example is of University of Regina research that aims to provide unique cost effective options to use the captured CO2 to produce value added products. One option involves CO2 reforming of natural gas, stranded gas and biogas to produce syngas, which is eventually used to produce synthetic fuels and fine chemicals.

Currently, syngas is produced by the partial oxidation of natural gas which uses oxygen (O2) extracted from the air through a very expensive process. The use of CO2 in our technology obviates the need to use an expensive O2-based process. It also obviates the need to separate out CO2 which is typically produced together (associated CO2) with natural gas or biogas thereby providing further cost savings.

Captured CO2 from the CCUS process will supply a large part of the needed CO2 for the reforming process, the other part coming from the associated CO2. The second option is provided through CO2-based sub/supercritical hydrothermal liquefaction of flax straw to produce fine chemicals. Again, captured CO2 from CCUS will supply the needed CO2.

As is well known, Saskatchewan, Canada, home of the University of Regina, is the largest grower and exporter of flax in the world. Once local farmers have harvested flax, they face a challenge regarding the disposal of the plant's hearty straw and strong stem which do not easily decompose into the soil. Burning such a large quantity of straw would cause unnecessary air pollution.




*Features of game-changing technology developed at the University of Regina*

## Carbon Capture, Utilization and Storage does work

One solution to this challenge is to use the flax straw as a biomass feed to produce renewable fuels and/or value added chemicals. Not only does the conversion of this abundant biomass help provide an alternative energy source, but it also minimizes CO2 emissions as its net CO2 contribution to the atmosphere is negligible.

In fact, researchers at the University of Regina have developed a process whereby the CO2 emitted from other large point sources can be used for converting flax straw to furfural, an important chemical used in various industrial applications. Furfural is used in the commercial production of furan, a major starting reagent for many specialty chemicals. Furfural is also used extensively in the refining of lubricating oil and to produce urea used for making fertilizer.

A further example is the research at the University of Regina which looks into understanding how people come to accept new technologies such as CCUS and other relevant topics through cognitive psychology and environmental technology. They are also looking at developing appropriate public policy based on technologies available. The objective is to identify public barriers to the acceptance of CCUS technology using qualitative and survey research in several communities.

Results of these studies will be used to craft interventions and engagement sessions to address the identified barriers. A study of best practices to achieve social license of CCUS technology internationally will be conducted and will inform the interventions and engagement sessions. Sessions will utilize several targeted methods (e.g. focus groups, deliberative democracy sessions, and other participatory processes), and will explore what business commitments, policy, regulatory, or legal provisions might be necessary to facilitate this social license.

## Summary

CCUS technology is a breakthrough and game-changing technology capable of drastically lowering the cost for CO2 capture. It addresses currently existing, and even anticipated, challenges and barriers towards commercial deployment of CCUS. It also provides viable and unique ways to utilize CO2 other than enhanced oil recovery and storage.

Another notable feature is that it deals with health, safety and the environment, public engagement, acceptance and public policy issues. Technological breakthroughs are examples of how research at the University of Regina is making a difference in the world, and demonstrates the University's commitment to research that has impact.

### More information

**www.uregina.ca**

# Assessing the economic impact of Alberta's emissions reduction funding

A Conference Board of Canada study quantifies the economic impact of investments in greenhouse gas-reducing technologies that include some funding from Alberta's Climate Changeand Emissions Management Corporation. **www.conferenceboard.ca**

**In 2009, as part of Alberta's climate change strategy, the Climate Change and Emissions Management Corporation (CCEMC) was established as an independent organization with a mandate to reduce greenhouse gas (GHG) emissions and help Alberta adapt to climate change through the discovery, development, and deployment of technology.**

The CCEMC receives money from the Climate Change and Emissions Management Fund, and, in turn, directs this money to support technology development at all stages of the innovation chain, from R&D to commercialization and deployment of emissions-reducing technologies.

The goal of this study is to quantify the economic impact of investments in transformative technologies that include some CCEMC funding and that are aimed at reducing GHG emissions. The wider repercussions on the overall economy of an investment in new technology can be estimated by using economic models. The economic impact analysis does not consider the operations of the CCEMC but, rather, the benefits of direct and leveraged investments. Moreover, this study does not consider the effect of CCEMC and related investments on reducing GHG emissions.

The CCEMC provided the investment data necessary to assess the economic impacts. This information included the value of projects undertaken or planned by various companies and organizations in which the CCEMC contributed a portion of the funding. Between 2011 and 2016, this investment is expected to amount to just over $1.3 billion (2007 $).

The Conference Board of Canada estimates that the total economic impact (including direct, indirect, and induced effects) of CCEMC and related investments from 2011 to 2016 will be more than $2.4 billion (2007 $), indicating that for each dollar invested, economic activity is lifted by nearly $1.90. In terms of the impact on jobs, we estimate that an additional 15,017 person-years of full-time-equivalent (FTE) employment will be added over the six-year period.

## CCEMC and Related Investments in New Technologies to Reduce Greenhouse Gases

| (2007 $ millions) | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | Total |
|---|---|---|---|---|---|---|---|
| **Wages and salaries, and other current spending** | 65.9 | 130.6 | 224.5 | 223.4 | 64.8 | 33.2 | 742.4 |
| **Non-residential construction investment** | 23.9 | 52.7 | 143.2 | 153.7 | 25.4 | 8.6 | 407.5 |
| **Machinery and equipment investment** | 9.5 | 21.7 | 59.4 | 63.1 | 10.7 | 3.7 | 168.1 |
| **Total** | 99.4 | 205.1 | 427.1 | 440.2 | 100.8 | 45.5 | 1318.1 |

*Sources: CCEMC; The Conference Board of Canada*

The impact on real gross domestic product (GDP) for Alberta is forecast to be $1.95 billion. This amounts to a multiplier of 1.5. In other words, for every dollar of investment through the CCEMC program, Alberta's economy will be lifted by $1.50. Additionally, total employment will rise by 12,244 FTE person-years from 2011 to 2016. At its peak, in 2014, total employment was up by roughly 5,200 jobs. This will also boost household income and retail sales—the latter up by a cumulative $790 million from 2011 to 2016. In turn, a lift to income will add $226 million to general government coffers.

Investments leveraged through the CCEMC program will result in additional supply-chain impacts in other provinces, as well. Ontario will benefit the most, with real GDP expected to rise by $240 million, while 1,231 person-years of FTE employment will be added to payrolls over the 2011 to 2016 period. British Columbia, Quebec, Manitoba, and Saskatchewan will also benefit from sizable lifts to economic activity and employment. The real GDP gains range from a forecast $22 million in Manitoba to $106 million in British Columbia, while the increases in person-years of FTE employment range from 134 to 696, respectively.

## Conclusion

The CCEMC has invested in and helped leverage additional funds for many new projects since its inception in 2009. These new investments are expected to total more than $1.3 billion (2007 $) in Alberta alone from 2011 to 2016. This direct contribution to the Alberta economy will lead to a $1.95-billion (2007 $) increase in the province's real GDP, through supply-chain and induced effects—a multiplier of 1.5. It will also result in the addition of more than 15,300 jobs, or 12,244 FTE person-years of employment.

The rise in output and employment will help generate a cumulative $1.2-billion increase in personal income in Alberta, as well as a $278-million cumulative increase in net operating surplus for corporations. Additional household tax revenues collected will amount to a total of $226 million over the six-year period.

Within the province, some of the largest supply-chain and induced impacts are occurring in the construction, manufacturing, and commercial services industries. However, not all of the supply-chain impacts are occurring in Alberta. Other provinces—Quebec, Ontario, Manitoba, Saskatchewan and British Columbia—are benefiting from Alberta's investments, and CCEMC and related investments of their own.

# EPRI's Carbon Capture Technology Innovation Program

EPRI's Carbon Capture Technology Innovation Program conducts long-term, basic R&D to analyze, quantify, design, and test existing and innovative CO2 capture options. This article describes the status and developments of this research in several areas.

By Abhoyjit S. Bhown, Electric Power Research Institute

Near-term carbon capture technologies employ aqueous amines to scrub CO2 from flue gas at fossil-fuel fired plants. These processes are projected to impose a load of ~15-20% on the net output of a coal-fired power plant to capture 90% of the CO2 generated by the power plant; compression of the captured, concentrated CO2 adds another ~8-10% to the load. These two loads, combined with the capital cost for capture and compression, are projected to nearly double the levelized cost of electricity (LCOE) for coal-fired plants relative to plants without carbon capture and storage (CCS).

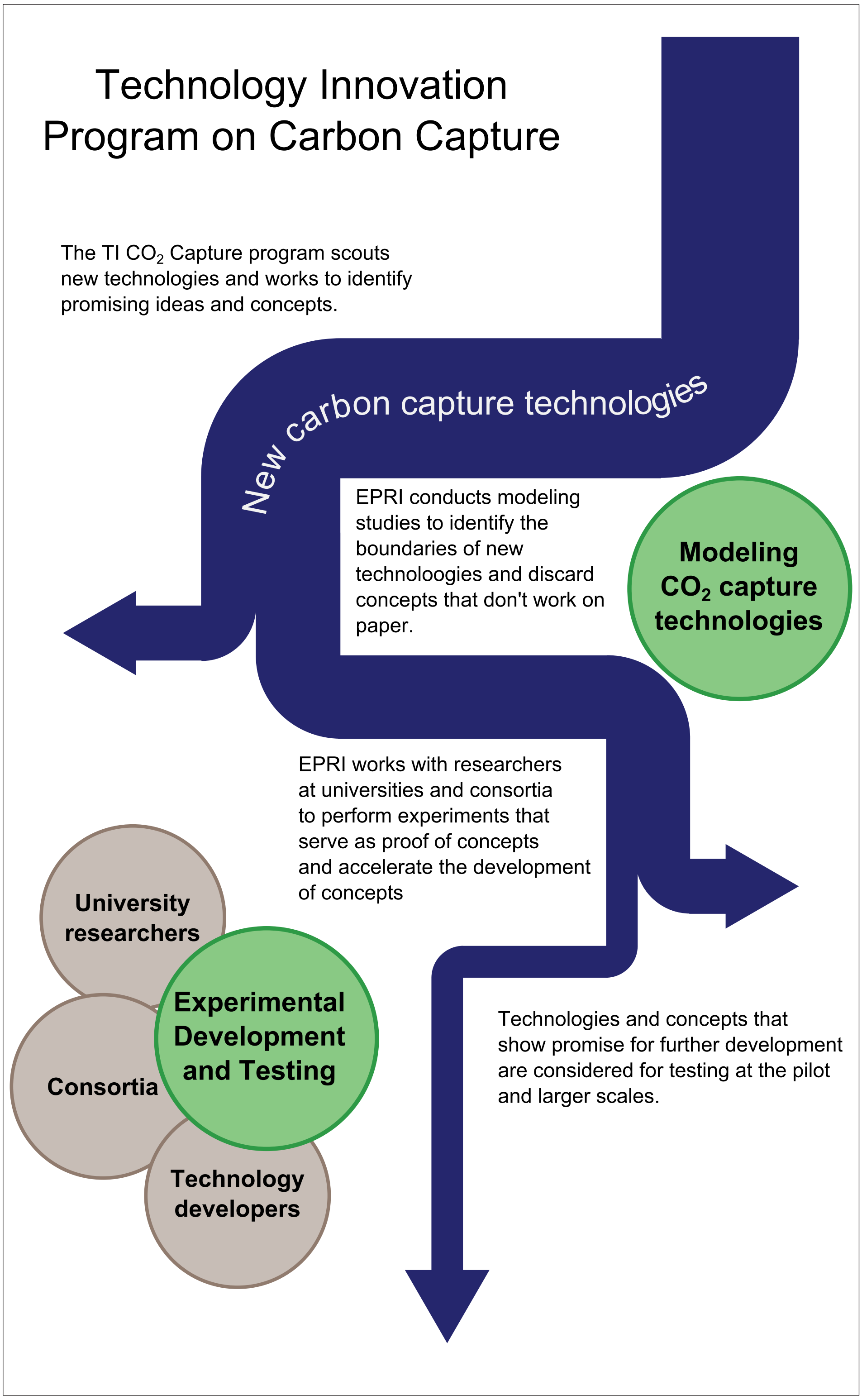
Innovations in CCS offering much lower energy consumption and capital cost are needed to drive down LCOE since coal-fired generation is projected to continue to dominate the world's energy supply. To achieve long-term climate goals, cost-effective CCS will also be required for gas-fired power plants.

To address this need, the Electric Power Research Institute (EPRI) launched its Carbon Capture Technology Innovation (TI) Program in 2009 to identify, develop, and advance revolutionary processes that reduce the cost of capturing CO2 from fossil power plants.

The TI Program conducts interdisciplinary modeling, materials screening, process evaluation, and proof-of-concept testing activities focused on concepts with the potential for revolutionary energy- and cost-performance improvements over near-term amine-based capture technologies.

Additional research is supported on advancing fundamental understanding of amine-based capture processes. Innovations ready for system-level validation are evaluated in the field, either at host plants or in testing facilities at the U.S. Department of Energy's National Carbon Capture Center (NCCC).

The TI Program's research includes over a dozen computational and experimental proj-



ects; six are highlighted here:

• Modeling and analysis of CO2 capture processes

• Metal-organic framework sorbents: process modeling and experimental synthesis

• Sorbent-polymer composites for CO2 capture

• Novel microporous materials and process cycles for adsorption-based CO2 capture

• Inertial CO2 extraction system

• Advanced membranes for post-combustion capture

## Modeling and Analysis of CO2 Capture Processes

This project involves first-principles modeling and analysis of all types of CO2 capture processes and their integration with existing and new fossil-fired power plants, including early-stage concepts and technologies being pursued both inside and outside of EPRI.

To date, EPRI researchers have used process modeling to characterize sorbent, solvent, and membrane capture mechanisms, and have conducted integration studies for post-combustion capture at simulated coal and gas plants. This work allows combined optimization of materials properties, capture processes, and power plant integration, offering deep insights with important R&D implications. For example, first-principles modeling of sorbent-based capture quantified adsorbent property parameters, such as the Henry's coefficient, that enable carbon capture with low energy consumption, helping narrow the search for promising materials (i).

First-principles modeling continues, while previously developed models are being applied and refined in other ongoing EPRI projects. For example, a low-pressure (LP) steam turbine model in GateCycle was applied to characterize how a power plant's net electric output is affected by steam extraction for thermally-driven capture systems operating at different pressures and flow rates. This relationship, which we call "imposed load," is important for determining the overall impact of CCS on power plant output, as both extraction steam pressure and its heat duty impact the net output of the power plant. By quantifying the effect of steam extraction, cycles and materials can be optimized in process design and plant integration studies to minimize the total lost work associated with a specific capture process.

In complementary work, an equilibrium model of an absorption system has been developed to evaluate lost work as a function of both solvent properties and system operating parameters (ii). Nuances of gas separation systems, impact of CO2 compression, and accurate steam cycle integration are all needed in order to optimize net electric plant output while varying aspects of the capture system.

Findings indicate that the optimal solvent to use in a given capture system is a function of that plant's equipment and operating parameters. Further, different solvents should not be compared based on their energy performance in the same system at the same conditions, because each solvent's system-specific performance will be optimized at different conditions. Instead, solvents should be compared based on their own optimal conditions in a capture process that has been optimized for that particular solvent.

## Metal-Organic Framework Sorbents: Process Modeling and Experimental Synthesis

EPRI's work to screen, develop, synthesize, and characterize adsorbents for CO2 capture is often done with collaborators at the University of California at Berkeley and Lawrence Berkeley National Laboratory and with support from U.S. Department of Energy's Energy Frontier Research Center and the Advanced Research Projects Agency—Ener gy (ARPA-E). Materials screened include zeolites, zeolitic imidazolate frameworks, porous polymer networks, and metal-organic frameworks (MOFs) (i, iii, iv). Results from the screening study are then used to design and synthesize materials to support scale-up testing. Because MOFs are very tunable, a wide range of materials with diverse physical properties can be evaluated, developed, and synthesized.

Both well-established and cutting-edge models are being applied for identifying the key properties of MOFs and other sorbents required to achieve the lowest possible energy requirements. Rapid computational screening of hundreds of thousands of possible materials enables focusing experimental synthesis on promising formulations and helps refine candidate materials and capture process designs to optimize performance.

EPRI and UC Berkeley have achieved significant progress by applying process modeling and large-scale screening to guide laboratory R&D. This work has included computationally simulating CO2 adsorption by novel MOF materials; screening these solid sorbent materials to identify the most promising candidates; determining the most relevant material properties, such as heat of adsorption, and optimal values for these properties; synthesizing materials that approach these optimal properties; and characterizing the synthesized materials.

In addition, several novel sorbents have been discovered and synthesized. These sorbents include an entirely new class of materials that undergo a disordered-to-ordered phase transition in the presence of CO2 that results in a step-change increase in adsorption under certain temperature and pressure conditions (iv). These new materials have the potential to dramatically lower the energy requirements for CCS.

Future activity involves scale-up of the MOF materials and testing in a suitable process configuration. EPRI will create a process flow diagram covering major power generation and capture system components and perform energetic analysis on newly synthesized materials. In addition, process models will continue to be applied in providing materials development guidance to ensure that the sorbents created will have the greatest potential for power plant applications.

## Sorbent-Polymer Composites for CO2 Capture

EPRI is developing and evaluating novel sorbent-polymer composite (SPC) materials for use as CO2 capture materials in humid environments. Embedding sorbents in a hydrophobic polymer could produce improvements to the carbon capture process by speeding heat transfer via direct steam heating and liquid water cooling (v). It also may allow the use of moisture-sensitive materials that could not otherwise be used in a humid environment. Together, these advances could decrease the energy use and cycle time of solid sorbent-based capture processes.

EPRI has teamed with W. L. Gore & Associates to successfully synthesize several candidate SPC materials, embedding selected sorbents into the hydrophobic polymer matrix. Ongoing testing at AECOM is determining the polymer's moisture rejection and its effects on the embedded sorbent's capture performance.

This is very early work, with the first SPC materials for CO2 capture synthesized in 2014. Future activities are contingent on results of the proof-of-concept testing currently under way at AECOM. If promising, EPRI will continue to determine the best sorbent and polymer properties for the SPC and to develop novel processes that optimize use of the unique hydrophobic properties of this material through plant integration studies.

Future activities would include larger-scale and multiple-cycle testing of the SPC to assess system configuration, degradation, and performance in real flue gas. If the SPC also shows promise for shielding otherwise moisture-sensitive materials from the effects of water and operation under humid conditions, EPRI will further work with materials developers to synthesize the optimal solid sorbent that can then be embedded into the SPC.

## Novel Microporous Materials and Process Cycles for Adsorption-Based CO2 Capture

This project is demonstrating the effectiveness of an innovative post-combustion CO2 capture technology, developed by InnoSepra under funding from the DOE's National Energy Technology Laboratory (NETL). The process utilizes a combination of novel microporous materials and a novel process cycle that result in rapid adsorption and energy savings. Projected benefits include a reduction in energy consumption and capital costs relative to near-term solvent-based CCS processes. Under the NETL award, InnoSepra has built and tested a 1-ton/day unit to determine the efficacy of the process. EPRI is providing independent energetic and economic modeling support.

EPRI has developed a model for evaluating the process from an energetic and system size perspective both on an equilibrium and dynamic basis. A second new model allows impacts on power plant output and electricity costs to be evaluated. These tools have been applied, along with results from the small pilot plant to determine the optimal process conditions such as cycle configuration, adsorption conditions, regeneration temperatures and pressures, bed sizes, and cycle timing.

InnoSepra's 1-ton/day unit has provided significant learning through the design, construction, and integration of the pilot with the flue-gas slipstream. Findings from EPRI modeling are being applied to guide operation of the pilot capture unit, and collected data provide an opportunity for model refinement. The efficacy and energy use of the unit will be the most telling results from this testing program.

## Inertial CO2 Extraction System

This project is furthering the development of a novel inertial CO2 extraction system (ICES) for carbon capture and conducting testing at the bench scale, developed by ATK under an ARPA-E award and now being developed primarily under an NETL award. The technology converts vapor-phase CO2 contained in flue gas to solid using supersonic expansion followed by inertial separation.

The ICES process uses stationary supersonic nozzles to accelerate flue gas to speeds between Mach 3 and Mach 4, which cools the flue gas and causes the CO2 to form solid particles. The process does not require use of a chemical intermediary in contact with the CO2 or flue gas. Instead, it relies on high-velocity, low-temperature flow dynamics to condense the CO2 in flue gas as a solid. The process also has the potential to have a much smaller footprint than existing capture technologies.

The current NETL project started in 2014 and focuses on controlling the nucleation, growth, and migration of the CO2 particles to the flow channel walls where they can be collected, purified, and pressurized. EPRI tasks include economic evaluation, as well as an advisory role in helping guide development and understand the impact of employing this technology on existing or new power plants.

## Advanced Membranes for Post-Combustion Capture

Many groups are developing novel membrane materials that have higher permeances and selectivities than existing commercial membranes. These advances have promise to reduce the cost of using membrane processes for CO2 capture, but next-generation membranes are still at the very early stages of development. Consequently, process designs that would use such membranes have not been evaluated under real-world conditions.

The goals of this effort are to compose models of CO2 capture processes based on membrane permeators, to apply the models to predict performance based on membrane properties, and to guide materials development. The first stage of the project supported experimental work at the University of Colorado Boulder, where researchers are developing novel membrane materials from polymerizable room-temperature ionic liquids (RTILs), under an ARPA-E award.

To better understand how different aspects of membranes and membrane operation affected performance, EPRI built a model of membrane modules in different flow configurations for use in a commercial process simulator. This model allows us to quantify how the selectivity and permeability of the membrane affects the power required and the size of the membrane needed to capture a certain amount of CO2. In addition, a first-order cost model is used to compare the relative cost of different post-combustion CO2 capture process designs for both coal- and gas-fired generation. Insights are applied to assist in the design and experimental synthesis of RTIL and other advanced membranes.

Work on gelled ionic liquid membranes concluded in 2014, with significant lessons learned and improved modeling capabilities. Continued EPRI modeling will address membrane properties and process design, including the evaluation of hybrid processes that combine membranes with other solvent, sorbent, or cryogenic separation technologies to achieve capture targets with lower energy and cost.

## Conclusion

EPRI's Carbon Capture Technology Innovation Program has focused on areas of carbon capture where long-term research is required and has the potential for breakthrough performance. Continued effort in these areas has been critical both in support and acceleration of promising external projects and the development of CO2 capture technologies at EPRI and elsewhere.

CCS remains a cornerstone of a decarbonized electrical generation fleet. Improving on existing materials, processes, and integration options, and discovering and developing novel CO2 capture options will be required to make this technology more cost-effective and to have less of an impact on new and existing fossil-fired power plants.

### More information

www.epri.com

# CCS recognised as "climate mitigation finance" by global financial institutions

Major financial institutions have recently published a list of guiding principles for future investments in clean energy in a document entitled 'Common Principles for Climate Mitigation Finance Tracking'.

By Bellona Europa

**With total assets amounting to roughly € 1,690 billion, this is an important step, providing more investor certainty ahead of the quickly approaching UN Climate Summit, COP 21, in Paris. Bellona welcomes the recognition of Carbon Capture and Storage (CCS) among the list of eligible activities, but is disappointed to see the document failing to exclude the redevelopment of unabated coal as a potential climate finance beneficiary.**

The document defines eligible 'climate mitigation activities' as those that promote 'efforts to reduce or limit greenhouse gas emissions or enhance greenhouse gas sequestration'. The range of activities eligible for the classification as climate mitigation finance include the deployment of renewable energy, lower-carbon and energy efficient generation, forestry and agricultural projects conducive of lower $CO_2$ emissions, and the application of CCS technology for power generation and industrial processes.

The inclusion of CCS is of crucial importance as this technology is an indispensable component of the solution to climate change, yet one in need of enhanced funding.

The document has been signed by top development banks in China, India, Brazil, South Africa, Japan and Mexico – which together control assets amounting to roughly €1,980 billion. Moreover, the list of guiding principles has been backed by the World Bank, International Development Finance Club and Agence Francaise de Developpement.

"Common methodologies across financial institutions are essential to build trust that climate finance is flowing" noted Rachel Kyte, World Bank Group Vice President and Special Envoy for Climate Change.

Development finance institutions have been tracking climate finance for only a few years, and their methods have varied, making global public finance numbers difficult to compare. The agreement on common definitions and methodologies among these institutions is therefore a milestone for climate financing.

Disappointing is, however, the fact that the document does not explicitly rule out the eligibility of unabated coal. Under the section for lower-carbon and efficient energy generation, the document states eligible activities as: "Energy-efficiency improvement in existing thermal power plant, industrial energy-efficiency improvements though the installation of more efficient equipment, changes in processes, reduction of heat losses and/or increased waste heat recovery" as well as "more efficient facility replacement of an older facility".

The document's 'guidelines' section gets closer to ruling out coal, but the language used remains too vague and is insufficient to achieve this. The text states "Greenfield energy efficiency investments are included only in few cases when they enable preventing a long-term lock-in in high carbon infrastructure, and, for the case of brownfield energy efficiency investments, it is required that old technologies are replaced well before the end of their lifetime, and new technologies are substantially more efficient than the replaced technologies. Alternatively, it is required that new technologies or processes are substantially more efficient than those normally used in greenfield projects".

## Slow progress

So far, progress observed across national governments has been slow. They have been unable to agree on common definitions on allocating climate finance and have failed to mobilise sufficient funding as promised to developing countries ahead of COP 21.

A formal pledge meeting for the Green Climate Fund (GCF) was held in late November and at the UN COP 20 Climate Summit in Lima a total of €9 billion was brought in. This, however, constitutes only about 1% of the amount pledged. What is more, the 9th meeting of the GCF Board in Songdo, Republic of Korea, last month, brought disappointment due to its failure to prohibit funding to coal power plants and the persistent ambiguity with regards to the lending criteria.

Even worse, the former UN climate chief Yvo de Boer has publicly made a statement defending the use of climate finance for unabated coal.

Bellona regards this as unacceptable, and calls for CCS to be rendered a pre-requisite to any continued use of coal. The distinction between unabated coal and coal with CCS must be clearly communicated.

At the EU-level, the agreement by EU Member States to increase funding dedicated to CCS demonstration projects after 2020 under a new, extended NER300 programme, the so-called Innovation Fund, is of crucial importance in sending a signal to investors that public funds will be available for future projects.

Nevertheless, in order to ensure it will be truly beneficial to CCS, the fund must be established as early as possible, to avoid a funding gap, and build on the lessons learnt from its predecessor, which was marked by a distorted awarding process based on inadequate criteria and lack of transparency. We are yet to see how the design of this envisaged fund develops – for more on this read Bellona's response to the ETS Directive consultation here.

## More information

Read Bellona's CCS coverage, including Norway and the Czech Republic's cooperation on CCS, at:

**bellona.org**

# Decarbonising British industry: why industrial CCS clusters are the answer

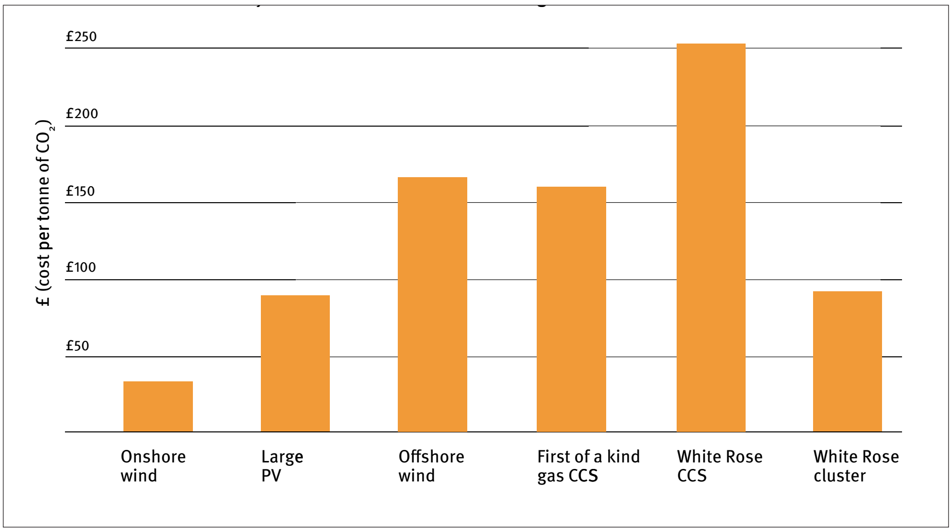
**In a new report, Dustin Benton from Green Alliance argues that using CCS for industry as well as power makes sense.**

**By Dustin Benton, Green Alliance**

The case for carbon capture and storage is increasingly confused. The IPCC suggests CCS makes quick, low cost decarbonisation much more feasible, and the prime minister recently declared the technology "absolutely crucial."

But a recent UCL study found that CCS makes little difference to the proportion of fossil reserves that cannot be burned. Less than a quarter of people support CCS in the UK, compared to the 80 per cent supporting renewables, and activists led anti-CCS protests at the recent Lima climate conference because they fear it will be used as a smokescreen for additional unabated fossil fuel use.

The picture on the ground is equally mixed. Progress on UK CCS deployment in the power sector is at least five years behind schedule. But interest is rising amongst industry, with Teesside leading the way, and the first commercial scale CCS project in the world has just begun operation, scotching the myth that the technology can't work.




*Cost of CO2 abatement by different low carbon technologies (Source: Green Alliance)*

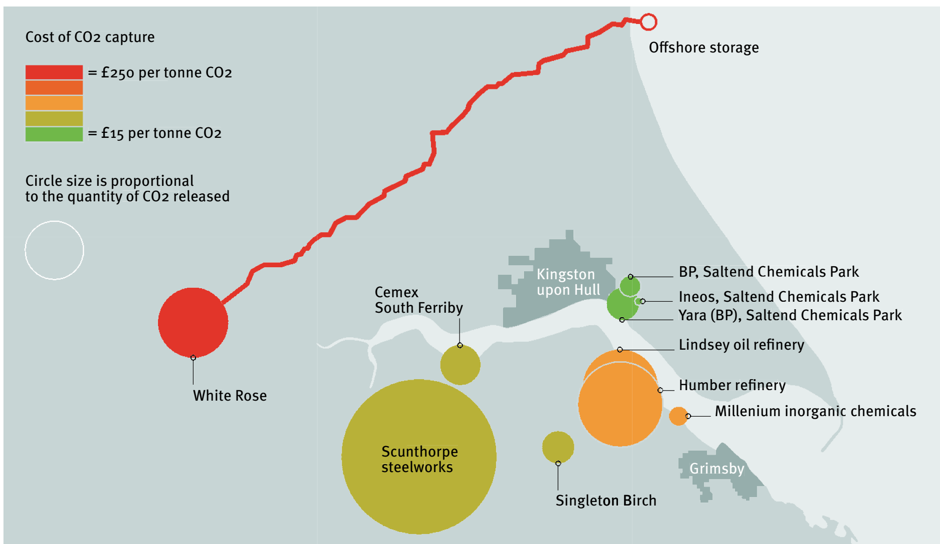
## The next government's decisions on CCS will have major implications

What should pragmatic politicians and policy makers make of these mixed messages? Whatever they decide matters because the next government's decisions on CCS will have major implications for both the power sector and industry.

The UK already has two CCS demonstration projects in the works. Both are expected to start construction toward the end of 2015, if approved by new ministers. The trouble is that they're expensive 'first of a kind' projects, potentially costing between £150 and £250 per tonne of avoided CO2. At this price there's a real risk that renewables or nuclear will seem like a better deal, and ministers will choose to delay CCS. For the power sector, this would mean giving up the UK's attempt to develop a three pronged approach to decarbonisation: developing nuclear, CCS, and renewables so they can compete on price by around 2030.

## CCS is the lead technology to decarbonise industry

But, whereas CCS is one (rather useful) option amongst many in the power sector, for




*Industries in the vicinity of White Rose will almost certainly need CCS to decarbonise successfully, and sharing pipeline and storage infrastructure would make it cheaper (Source: Green Alliance)* energy intensive industry it is clearly the lead technology for carbon mitigation. In fact, it's hard to see how some industries will decarbonise their process emissions without it.

This complicates the decisions on power sector CCS: how much should we pay for technology development? Should we pay more for power if it helps to commercialise an essential technology for industry? And how much should industry pay?

Our new analysis shows that using the infrastructure developed for power sector demonstration projects to create wider industrial CCS clusters would alleviate some of the pressure, bringing the cost of CCS in line with other large scale low carbon technologies:

The map below shows the large volume of relatively low cost CO2 available in the vicinity of the proposed White Rose power plant. Capturing this as part of a cluster could cut the cost of CCS per tonne by nearly two thirds, and increase the amount of carbon abated nearly nine-fold, compared to the demonstration project on its own. Equally importantly, such a cluster would help industry to compete in a much lower carbon economy.

### CCS for industry will help to bring down the overall cost

There is a catch. Building a whole CCS cluster would cost around four times in total as much as a single project. And, in absolute terms, the numbers are big: £20 billion in total expenditure for the cluster, compared to £5 billion for the power project alone. This isn't a uniquely large amount of money: other low carbon projects, like the Hinkley C or large offshore wind farms, are comparable in cost. But our analysis shows that current grants, EU funds and electricity contracts for difference won't be able to support a cluster.

Our conclusion is that government should raise its bets: spending more on CCS looks very likely to reduce the cost of decarbonisation. The key question for policy makers is how to allocate the costs across the electricity and industrial sectors, and how to refocus policy to foster competition between different means of capturing CO2 to drive down the costs for industry.

### More information

The full report, "Decarbonising British industry: why industrial CCS clusters are the answer" can be downloaded at:

**green-alliance.org.uk**

## Projects and policy news

### UK awards £4.2m for CCS research at Grangemouth

**www.decc.gov.uk**

**The UK and Scottish Governments have given £4.2 million in-principle funding to support Summit Power's proposed CCS coal-gasification power station located in Grangemouth.**

The funding, £1.7 million from Department of Energy and Climate Change (DECC) and £2.5 million from the Scottish Government, will allow Seattle-based Summit Power Group to undertake substantial industrial research and feasibility studies with the ultimate objective of designing, siting, financing, and building their proposed Caledonia Clean Energy Project.

A detailed programme of research and development work will now be undertaken over an 18 month period to advance the engineering design of the project. The findings of the industrial research feasibility work will be shared across industry and academia, increasing understanding of how to develop and deploy CCS at commercial scale.

For the first time, this large scale low-carbon power project aims to combine and integrate coal gasification, 570 MW power generation, and carbon capture technologies in a single facility.

The proposed power station will be fitted with CCS technology designed to capture 90% of CO2 emissions which would then be transported via existing on-shore pipelines and existing sub-sea pipelines for permanent geological storage 2km beneath the North Sea. The funding is in principle and conditional upon agreeing the terms of the grant.

# Projects and policy news continued

## ETI report shows UK can build 10 GW of CCS by 2030

**www.eti.co.uk**

**A new Energy Technologies Institute report shows that Building a 10 GW scale Carbon Capture and Storage sector by 2030 in the UK is feasible and affordable.**

By developing co-ordinated clusters and storage hubs, the sector could be capturing around 50 million tonnes of $CO_2$ in 2030 from power stations and industry.

The report shows that the UK has an opportunity to build a CCS sector capable of reducing the costs of meeting its carbon targets, by exploiting the UK's unique offshore engineering capabilities, safeguarding the future of key energy-intensive industries.

Written in partnership with Element Energy and Poyry - "Building the UK Carbon Capture and Storage Sector by 2030 – Scenarios and Actions" identifies the practical steps needed over the period to 2030 to build an effective CCS sector.

It suggests three possible scenarios that would allow CCS to realise its long term potential and play a key role in decarbonising the UK's energy sector with the development of around 10 GW of capacity by 2030.

Key conclusions from the report include:

- Developing a 10 GW scale CCS sector by 2030 is feasible and affordable through a number of different pathways, if co-ordinated clusters are developed.

- This scale of CCS deployment could capture and store around 50 million tonnes of $CO_2$ emissions a year from power and industry by 2030, enabling CCS to develop in the 2030s to the optimal scale suggested by longer term analysis of the UK energy system.

- Infrastructure is key to future development. Enabling projects to use the pipes and storage sites developed by the first two projects supported by the Department of Energy and Climate Change will help reduce costs and increase strategic build out options

- Any delay to CCS roll-out increases costs through the need to deploy higher cost technologies to cut emissions and failing to deploy CCS at all could double the annual cost of carbon abatement by 2050

George Day, the ETI's Head of Economic Strategy and the report's author, said:

"Our analysis of the UK's future energy system has consistently highlighted the importance of CCS in helping the UK meet carbon targets effectively and affordably. Developing CCS can also build on the country's existing offshore engineering capabilities and safeguard the future of key energy-intensive industrial clusters and thousands of jobs.

"Apart from its role in power generation, CCS can capture industrial emissions at low cost, provide flexible low carbon energy for industry, transport and heat through gasification and deliver high value negative emissions when combined with bioenergy.

"The scenarios are not recommendations – but we believe all three show that it is feasible and affordable for the UK to develop around 10GW of CCS capacity by 2030.

"This work shows the importance of moving quickly to develop a pipeline of projects for investment throughout the 2020s following on from the first two government-supported projects. We need stronger policy and market signals to resolve uncertainties for investors, and early investment to appraise new storage sites for $CO_2$ below the North Sea."

As well as identifying possible scenarios and actions needed to meet the 2030 ambition, the report also highlights the consequences of delaying development of this level of capacity beyond 2030 which would expose the UK to substantial cost and deployment risks in meeting carbon budgets.

Last month the ETI published an Insight report, "Targets, Technologies, Infrastructure and Investments – Preparing the UK for the Energy Transition" which concluded that the UK can implement an affordable transition to a low carbon energy system over the next 35 years by developing, commercialising and integrating technologies and solutions that are already known, but underdeveloped. It highlighted the underlying enormous potential and value in CCS and bioenergy in delivering a low carbon future.

It also warned that decisions taken in the next decade are critical in preparing for the transition and crucial decisions must be made about the design of the UK future energy system by 2025 to avoid wasting investment and ensure the 2050 targets remain achievable.

Luke Warren, Chief Executive of the Carbon Capture and Storage Association welcomed the findings of the report.

"This is a crucial year for CCS: The current Competition to develop the UK's first CCS projects – the White Rose project at the Drax site in Yorkshire and the Peterhead Gas CCS project in Scotland – is progressing with detailed engineering work, and final investment decisions are expected around the end of this year," he said.

"But if the UK is to benefit from commercial CCS then, as today's report finds, it is essential that the next Government successfully concludes the current Competition and delivers both projects. These projects will form the foundations upon which the UK builds a successful CCS industry."

"The report also highlights the importance of avoiding delay in the development of CCS; which would otherwise expose the UK to substantial costs and deployment risks in meeting carbon budgets."

"The UK is world-leading in developing an enduring policy framework to support CCS alongside renewables and nuclear under the Electricity Market Reform programme. What is now needed is for the Government to use policy to actually deliver a steady roll-out of CCS projects, which will enable CCS to become cost-competitive with other low-carbon technologies. Around the world many of our competitor economies are advancing this technology; we must not be left behind"

## Correction

In the article, "How to build a 10GW CCS Sector in the UK by 2030?" which appeared in the Mar / Apr 2015 edition of the magazine, the summary table on Page 3 contained some preliminary figures. The pdf version of this issue has been updated with the correct figures and is available to download free from our website (until the end of June 2015). The full report can also be downloaded from: **www.eti.co.uk**

## CCP launches phase four: mission to advance CCS for the oil and gas industry

**www.co2captureproject.org**

**The CCP (CO2 Capture Project) is now in its fourth phase, having officially extended its program by a further four years, beginning February 2015 and concluding at the end of 2018.**

This partnership of major energy companies is now in its fifteenth year and will continue to develop pioneering CO2 capture and storage (CCS) technology research and knowledge for potential application in the oil and gas industry.

The CCP4 program aims to develop further research and understanding of CO2 capture solutions in the scenarios identified from previous CCP phases (refinery, heavy oil and natural gas power generation), together with a new scenario – CO2 separation from natural gas production.

Within CO2 storage, the CCP4 program will continue to demonstrate safe and secure geological containment through field-based monitoring and the development of robust intervention protocols.

The CCP4 program follows on from the successful achievements of its previous phase. Key highlights from CCP3 include:

• Demonstration of oxy-firing capture technology at a refinery research facility in Brazil

• Demonstration of oxy-firing capture technology at a heavy oil extraction facility in Canada (due to complete later in 2015)

• Economic baselines for oil refinery, heavy oil and natural gas scenarios finalized

• Modular borehole monitoring system successfully deployed at Citronelle Dome (Alabama, US) site

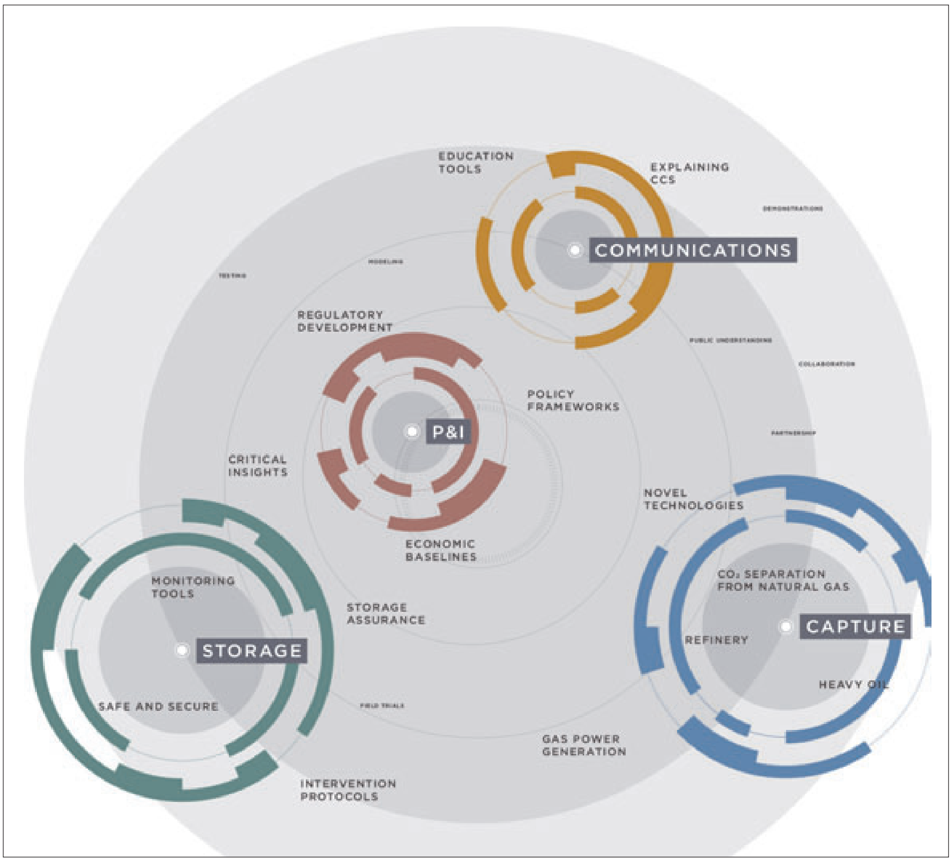
• Contingencies study modeling completed with significant conclusions drawn

• CO2 impurities study showing impact on underground CO2 plume behavior completed

CCP Chairman, Nigel Jenvey, comments:

"We are delighted to take CCP's work into the next phase, advancing viable and sustainable CCS solutions for the oil and gas industry. Our focus is on improving cost efficiencies of emerging technologies, assessing novel technologies with great potential, and building the science and engineering expertise around both storage and capture.

We are also open to further collaboration with other CCS research, development and demonstration programs. Prospective new members are welcome to contact CCP to gain further details of the program and membership details."




*The CCP4 program aims to develop further research and understanding of CO2 capture solutions in the scenarios identified from previous CCP phases (refinery, heavy oil and natural gas power generation)*

The CCP (CO2 Capture Project) is a partnership of major energy companies working together to advance the technologies that will underpin the deployment of industrial-scale CO2 capture and storage (CCS).

Since CCP's formation in 2000, it has undertaken more than 150 projects to increase understanding of the science, economics and engineering applications of carbon capture and storage.

The partnership works alongside specialists from industry, technology providers and academia to advance technologies, improve operational approaches and help make CCS a viable option for CO2 mitigation in the oil and gas industry. CCP has been working closely with government organizations – including the US Department of Energy, European Commission and 60+ academic bodies and global research institutes.

The members of CCP's fourth phase are: BP, Chevron, Petrobras and Suncor.

## Shell Canada funds CCS exhibit

**www.shell.ca**

**Shell Canada is contributing $450,000 to the TELUS World of Science, Edmonton (TWOSE) to fund its on-site school program, and unveiled a new interactive CCS exhibit.**

The funding will be directed to the Science Centre's on-site school program, and is distributed over three years. The interactive CCS display is designed to help showcase the technology, and specifically Quest, the first commercial-scale CCS project in the world for an oil sands operation.

The interactive experience invites TWOSE visitors to take a journey more than two kilometres underground to the rock formation into which the Quest CO2 will be injected and permanently stored.

“Supporting education and developing science literacy is a major focus of our social investment program,” says Stephanie Sterling, Shell’s General Manager, Community and Indigenous Relations. “The science centre’s school field trip program is designed to teach about science through hands-on learning opportunities and reaches on average more than 160,000 students per year. We are delighted to support a program that is focused on making science fun for kids and inspiring innovative thinking.”

“Advancing knowledge is a core aspect of our science centre, and we are grateful for this partnership which allows us to continue to serve the community,” says Alan Nursall, President and CEO, TWOSE. “The support of our school programs ensures our scientists can deliver programs which engage thousands of students. The carbon capture and storage exhibit adds value for all our guests to better understand this technology.”

“Science, technology and innovation are all core to what Shell and our industry does. In addition to providing funding for science education we are able to bring an interactive experience to the facility that is designed to enhance understanding about how CCS technology works and the work Shell is doing to advance CCS through the Quest project,” says Sterling.

“As we get closer to starting up Quest later this year we want to show Albertans how CCS works and demonstrate Canada’s leadership in helping to pave the way for future GHG-reducing CCS projects around the world.”

## China Steel Corporation invests in LanzaTech

**www.lanzatech.com**

**Taiwan's largest integrated steel maker, China Steel Corporation (CSC), has approved a 1400M TWD ($46M USD) capital investment in a LanzaTech commercial ethanol facility.**

This follows the successful demonstration of the revolutionary carbon recycling platform at the White Biotech (WBT) Demonstration Plant in Kaohsiung using steel mill off gases for ethanol production.

LanzaTech's gas fermentation process uses proprietary microbes to capture and reuse carbon rich waste gases, reducing emissions and pollutants from industrial processes such as steel manufacturing, while making fuels and chemicals that displace those made from fossil resources.

In November 2012, China Steel Corporation (CSC) and LCY Chemical Corporation formed a joint venture, White Biotech (WBT), as part of a Green Energy Alliance with LanzaTech. The resulting demonstration plant met or exceeded all ethanol production milestones and the CSC Board have formally approved the capital to move to commercial scale. A 50,000 MT (17M Gallons) per annum facility is planned for construction in Q4 2015, with the intention to scale up to a 100,000 MT (34M Gallon) per annum commercial unit thereafter. Initial product focus will be industrial ethanol and gasoline additives, with plans for increased product diversity utilizing LanzaTech's unique microbial capability.

"LanzaTech will help create a more sustainable future by recycling carbon from the steel mill and enabling green growth through production of useful everyday products. We will have to work even closer to complete this important project," said Dr. Jo-Chi Tsou, Chairman of CSC.

"CSC has long been a champion of utilizing new technologies to create a better future and we are proud to help make this a reality," said LanzaTech CEO Jennifer Holmgren. "We need to keep fossil resources in the ground and carbon recycling is one way we can achieve this. If we are to keep within our global carbon budget we need all technologies to contribute and, more importantly, we need forward looking industries and organizations, such as CSC, to bring these technologies to market."

## Mineral Products Association responds to UK cement carbon reduction roadmap

**www.mineralproducts.org**

**The Mineral Products Association (MPA) has responded to the publication of the Government’s 2050 carbon reduction roadmap for the UK cement sector.**

The report, commissioned by the Department of Energy and Climate Change (DECC) and the Department for Business, Innovation and Skills (BIS) and prepared by Parsons Brinckerhoff and DNV GL, in collaboration with those Departments and industry, sets out potential pathways for carbon reductions under a range of scenarios, including with and without CCS.

As published, the report is incomplete as more work needs to be done to characterise and cost the various decarbonisation options. MPA would have preferred to see this work completed before publication to ensure clarity and certainty on the work ahead, but will continue to cooperate with the Government on the development of the Roadmap.

Commenting on the report, Dr Pal Chana, Executive Director MPA, said, “The UK cement industry has taken a leading position in exploring long term trajectories for carbon reduction in what is a highly energy intensive industry. The UK cement sector has already made major strides in reducing carbon emissions and, as part of this, became the first in the global cement industry to publish its own national carbon reduction roadmap in 2013.

This new report, commissioned by DECC and BIS, is the Government’s next steps on our pioneering work and the MPA and its member companies have cooperated closely with the project team to identify potential technologies and reduction pathways.”

“The UK cement industry set itself, in its own roadmap, the ambition of cutting greenhouse gas emissions by 81% over 1990 (Kyoto Protocol baseline year), if CCS can be technically and economically deployed; and of cutting greenhouse gas emissions by 62% without CCS, subject to other aspects outside of their control also being delivered, such as decarbonisation of the electricity grid. The Government roadmap is consistent with the industry’s ambitions and presents a range of pathways and scenarios comprising a number of technological interventions which have yet to be fully costed.

“UK cement producers will work with DECC and BIS to explore the feasibility of the new pathways, but as the report itself acknowledges, the measures to cut carbon emissions need to be technically feasible and economically viable. MPA believes that carbon reductions need to be achieved while maintaining the competitiveness of domestic manufacturers. There is no point in making it more expensive to produce cement domestically than it is to import cement from other countries, as this simply displaces the carbon emissions somewhere else – a classic case of ‘carbon leakage’.”

# HTC CO2 Systems' heavy oil CO2 capture plant

HTC CO2 Systems Corp. has installed its first CO2 capture plant on a Steam Assisted Gravity Drainage boiler for heavy oil enhanced oil recovery applications.

By Dr. Ahmed Aboudheir, HTC System Corp.

**HTC CO2 Systems Corp. designed, constructed, and installed a 30 tonne per day CO2 capture facility from a 50-million Btu/h once-through steam generator located at Husky Energy's Pikes Peak South SAGD operations, Saskatchewan, Canada. The HTC Low Cost Design, LCDesign™, approach has been taken to reduce the capital and operation expenditures.**

The LCDesign™ is based on efficient process configuration, low energy solvent, optimum operating parameters, and modular approach for unit fabrication and delivery. The application of LCDesign™ approach to design and build CO2 capture plants is proven to meet the required production capacity at minimum emission to atmosphere, minimum effluent/solid waste for disposal, lower capital and operation expenditures.

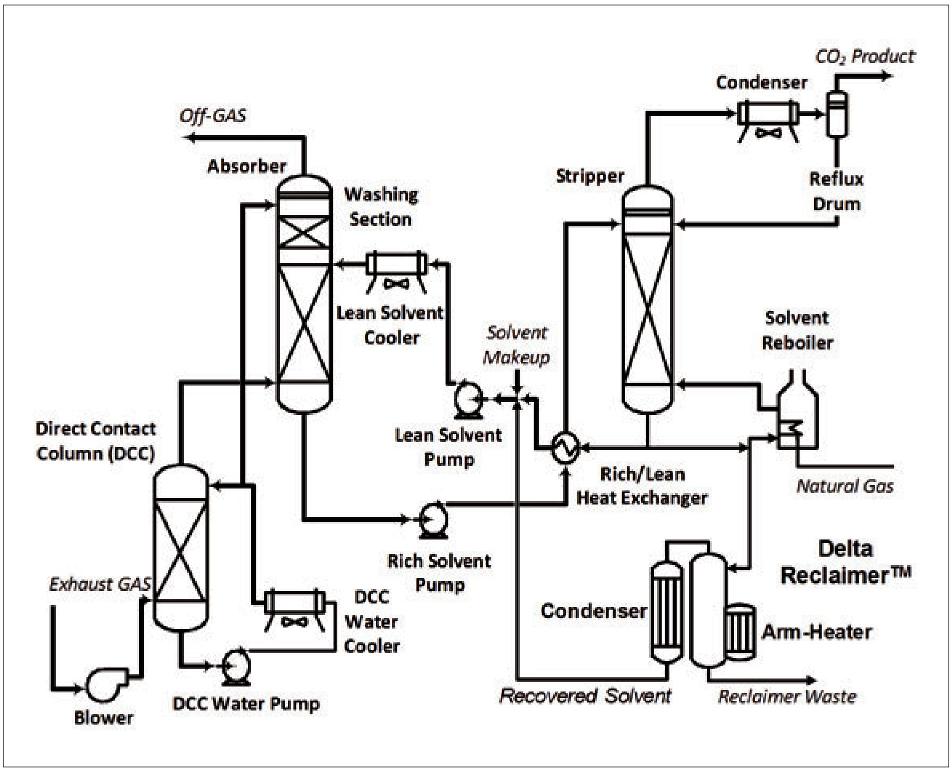



*Figure 1 - Process Flow Diagram for CO2 capture from exhaust gases of OTSG*

## CO2 production cost from SAGD boilers

The post-combustion carbon dioxide (CO2) capture from gaseous mixtures by means of liquid absorbents is a proven technology and will continue to be one of the leading techniques for capturing CO2 for many decades to come. Canada has proven enhanced oil recovery projects based on capturing CO2 from coal fired and coal gasification plants.

Recently, the oil industry has been investigating ways to access CO2 nearer to the oil fields in a more costly manner, and has been looking into the possibility of capturing CO2 from exhaust gases of many existing Steam Assisted Gravity Drainage (SAGD) operations located throughout Western Canada.

Once Through Steam Generation (OTSG) boilers are large natural gas based boilers that are used to generate steam for injection into heavy oil formations to decrease the viscosity of the oil to allow the oil to be pumped. As shown in Figure 1. SAGD is an advanced form of steam stimulation in which a pair of horizontal wells are drilled into the oil reservoir, one a few metres above the other. Steam is continuously injected into the upper wellbore to heat the oil and reduce its viscosity, causing the heated oil to drain into the lower wellbore, where it is pumped out.

*LCDesign™ Plant located at Husky Pikes Peak*

*Column transportation to the site*

In their March 2009 report, the Alberta Carbon Capture and Storage Development Council, concluded that the cost of capturing $CO_2$ from SAGD boilers to be in the range of $175 to $230 per tonne. This cost was shown as significantly higher than the cost from any other source indicating that there was a technology/costing gap as a barrier to implementing $CO_2$ capture from thermal in-situ oil sands operations. The high costs illustrated in the report were attributed to the limited availability of utilities, fabrication standards for classified area, and the high cost for installation at remote oil fields.

To overcome some of these cost challenges, HTC CO2 Systems Corp. looked into a new approach to design and fabricate $CO_2$ capture plants, which was based on proven oil field manufacturing techniques. Brand named the "Low Cost Design" (LCDesign™), this low cost $CO_2$ capture approach takes into consideration the following main design improvements:

- Building the unit in factory setting, using skids to allow the modules to be transported to the field for installation – Thus substantially reducing field labour, the major cost of the unit.

- Using standard off the shelf parts

- Simplified process flowsheet for the $CO_2$ capture process to reduce CAPEX and simplify the plant operation

- Formulated solvent to meet the production capacity and the cleanup targets at minimum utility consumptions

- Integrated Delta Reclaimer System to optimize solvent performance

- Optimum operating parameters/conditions in order to minimize the operation costs

- Testing the unit in a controlled environment prior to shipment

Initially to prove out the initial design concepts, an Alberta Government and Devon Energy funded a Front End Engineering and Design (FEED) study was completed to assess the cost of capturing 1000 TPD of $CO_2$ from the exhaust of three OTSG, 250 million Btu/h capacity each, at Devon Energy's Jackfish-1 thermal in-situ operations, in Alberta, Canada.

The publically available study concluded the total CAPEX estimate for this facility, within +/-15% accuracy, was $83 million (Canadian Dollars), which included project management, engineering, purchased equipment, shop fabrication cost, and material and labour cost for installation and commissioning.

Based on the CAPEX estimate, using a weighted average cost of capital of 8%, and a twenty-year project life the capital component of the capture cost of $CO_2$ would be less than $37/tonne, assuming 95% plant availability and long-term average operation at 85% of design capacity. Adding an estimated operating cost of approximately $30/tonne of $CO_2$, the indicative total $CO_2$ capture cost is under $70/tonne of $CO_2$ captured from SAGD Boilers, significantly less than earlier estimates of $175- $230/tonne of CO2p

## Modular plan for CO2 capture from SAGD boiler

On the basis of the promising Devon results, HTC was commissioned by Husky Energy, and the Alberta and Saskatchewan Governments to design, constructed, and installed a 30 tonne per day $CO_2$ capture facility at Husky Energy's Pikes Peak South SAGD operations, Saskatchewan, Canada.

The $CO_2$ is captured from a 50-million Btu/h once-through steam generator (OTSG) and piped for enhanced oil recovery at Husky's nearby heavy oil field. HTC took a modular design approach using its LCDesign™ design philosophy to meet the required production capacity within these project constraints at minimum emission to atmosphere, minimum effluent/solid waste for disposal, reduced CAPEX, and reduced OPEX.

Table 1 shows the exhaust gas condition and composition from the OTSG, 50 million Btu/h. As it can be seen from this table, about 50% of exhaust gases output is used to produce 30 tonne per day $CO_2$ for EOR applications in nearby heavy oil field. The exhaust gases is very clean and there is no need to apply any pre-treatments except cooling the ex-

## Table 1 - Exhaust gases composition and conditions from 50 million Btu/h OTSG boiler

| **Description** | **Value** |
|---|---|
| Total Exhaust gases Flow Rate OTSG [Sm3/h] | 16,700 |
| Exhaust gases Rate to CO2 Capture Plant [Sm3/h] | 9,010 |
| Inlet Temperature, [°C] | 148 |
| Inlet Pressure [kPa (a)] | 94 |
| **Composition** | |
| $N_2$ [mole%] | 70.75 |
| Ar [mole%] | 0.85 |
| $O_2$ [mole%] | 2.47 |
| $CO_2$ [mole%] | 8.30 |
| $H_2O$ [mole%] | 17.62 |
| $NO_x$ [ppmv as $NO_2$] | 49 |

haust gases from 148 °C to 35 ±5 °C before the $CO_2$ absorption process with the HTC formulated solvent, DeltaSolv™.

Figure 1 shows the HTC overall process flow diagram recommended for the $CO_2$ capture from OTSG. A simplified process flowsheet was selected to reduce the CAPEX and to simplify the operation of the plant. The plant consisting of the following main equipment:

• The direct contact column (DCC) is mainly required to condition and cool the exhaust gases temperature before entering to the absorber column. The DCC will produce excess water from water condensation during the cooling process, which can be used for water make-up and it would make the plant self-sufficient in term of water consumption. In this case, no need for the process water except for the initial fill and the start-up of the plant. In our current process configuration, this excess water from DCC is sent to the top of the washing section as water make-up and to wash/cool the off-gas in order to reduce the solvent loss considerably by more than 98% and to maintain the plant in water balance.

• The absorption/stripper configuration is used to capture the $CO_2$ from the exhaust gas efficiently using the HTC formulated solvent, DeltaSolve™, which is an engineered solvent that has high absorption rate, high $CO_2$ loading, low degradation rate, low corrosion rate, low volatility, and requires minimum energy for solvent regeneration.

• The skid mounted solvent reboiler is designed as a vertical tube exchanger heated with natural gas fired burner. The reboiler is designed to heat the solvent at pre-set temperature in order to avoid creating hotspots that may cause thermal degradation of the solvent. In this case no need to use the steam from the OTSG for the reboiler duty.

• Since no cooling water available on site, standalone air-cooled heat exchangers are used for the stripper overhead condenser unit, the DCC water cooling unit, and lean solvent cooling unit.

• The skid mounted Delta Reclaimer™ is designed to maintain the solvent absorption efficiency by removing all the high boiling degradation products, heat stable salts, and suspended solids from the solvent.

• All the instruments and equipment such as lean/rich heat exchanger, filters, and pumps, are accommodated in one process building, 24 × 80 ft., which consists of two parts during transportation, each is 24 × 40 ft.

## Table 2 - Effect of design approach on the operating and capital expenditure

| Description | Option A | Option B | Option C |
|---|---|---|---|
| **Reboiler Energy, MJ/Kg CO2** | < 2.1 | < 2.6 | < 3.2 |
| **Formulated solvent** | DeltaSolv-2™ | DeltaSolv-2™ | DeltaSolv-3™ |
| **Heat Integration** | Yes | No | No |
| **Plant Configuration** | Simple | Complex | Simple |
| **Number of control loops** | High | High | Low |
| **Plant Operation** | Complex | Complex | Simple |
| **Number of Operators** | High | High | Low |
| **Solvent circulation rate** | High | High | Low |
| **Equipment Size** | Large | Large | Small |
| **Capital expenditure** | High | High | Low |
| **Operating Expenditure** | Low | Low | Low |

Table 2 represents the effect of the overall design approach on the operating and capital expenditures of the $CO_2$ capture plants. Without heat integration between the $CO_2$ plant and the adjacent industry heat sources, low operating and capital expenditures can be achieved on the expense of increasing the reboiler heat duty slightly at less than 3.2 MJ per Kg captured $CO_2$.

The reboiler heat duty can be reduced further by heat integration if accessible onsite as shown for option A, which shows reboiler heat duty of less than 2.1 MJ per Kg captured $CO_2$.

The main findings from the FEED study of the 1000 TPD $CO_2$ capture facility and from building the 30 TPD $CO_2$ capture facility were:

• It is feasible to capture $CO_2$ from the OTSG exhaust gases and use for enhanced oil recovery,

• It is feasible to design, build and deliver $CO_2$ capture plants for SAGD operation in modular forms,

• The production capacity and the clean-up targets can be easily achieved at minimum $CO_2$ production cost using formulated solvent, advanced but simplified process configuration, and optimum operating conditions.

### More information

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# New material captures carbon at half the energy cost

UC Berkeley chemists have developed a material that can efficiently remove carbon from the ambient air of a submarine as readily as from a coal-fired power plant.

**The material then releases the carbon dioxide at lower temperatures than current carbon-capture materials, potentially cutting by half or more the energy currently consumed in the process. The released CO2 can then be injected underground, or, in the case of a submarine, expelled into the sea.**

The work is described in a paper in Nature, "Cooperative insertion of CO2 in diamine-appended metal-organic frameworks"

"Carbon dioxide is 15 percent of the gas coming off a power plant, so a carbon-capture unit is going to be big," said senior author Jeffrey Long, a UC Berkeley professor of chemistry and faculty senior scientist at Lawrence Berkeley National Laboratory. "With these new materials, that unit could be much smaller, making the capital costs drop tremendously as well as the operating costs."

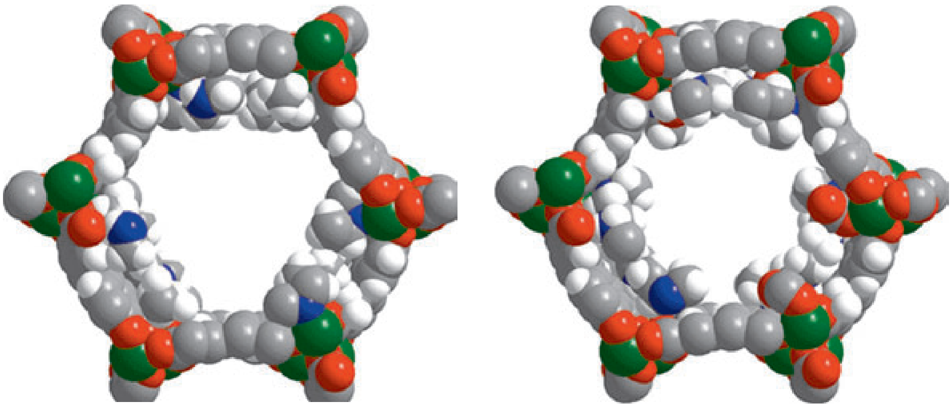
The material, a metal-organic framework (MOF) modified with nitrogen compounds called diamines, can be tuned to remove carbon dioxide from the room-temperature air of a submarine, for example, or the 100-degree (Fahrenheit) flue gases from a power plant.

"It would work great on something like the International Space Station," Long said.

Though power plants are not now required to capture carbon dioxide from their emissions, it will eventually be necessary in order to slow the pace of climate change caused by fossil-fuel burning. If the planet's CO2 levels rise much higher than they are today, it may even be necessary to remove CO2 directly from the atmosphere to make the planet livable.

## From flue gas to submarines

Power plants that capture CO2 today use an old technology whereby flue gases are bubbled through organic amines in water, where the carbon dioxide binds to amines. The liquid is then heated to 120-150 degrees Celsius (250-300 degrees Fahrenheit) to release the gas, after which the liquids are reused. The entire process is expensive: it consumes about 30 percent of the power generated, while sequestering underground costs an additional though small fraction of that.



*The view is a cross section through one of the pores of a metal-organic framework, showing diamine molecules (containing blue nitrogen atoms) attached to metal (manganese) atoms (green). Carbon dioxide molecules (grey carbon atoms with two red oxygen atoms) bind through a cooperative mechanism akin to a chain reaction along the pore surfaces. Some H atoms (white) are omitted for clarity. (Graphic by Thomas McDonald, Jarad Mason, Jeffrey Long/UC Berkeley)*

The new diamine-appended MOFs can capture carbon dioxide at various temperatures, depending on how the diamines are synthesized, and releases the CO2 at only 50 C above the temperature at which CO2 binds, instead of the increase of 80-110 C required for aqueous liquid amines. Because MOFs are solid, the process also saves the huge energy costs of heating the water in which amines are dissolved.

MOFs are composites of metals — in this case, magnesium or manganese — with organic compounds that, together, form a porous structure with microscopic, parallel channels. Several years ago, Long and his lab colleagues developed a way to attach amines to the metals in an MOF to produce pores of sufficient diameter to allow CO2 to penetrate rapidly into the material. They found that MOFs with attached diamines are very different from other carbon-capture materials, in that the CO2 seems to load into the material very quickly at a specific temperature and pressure, then come out quickly when the temperature is raised by 50 C. In the new paper, UC Berkeley graduate students Thomas McDonald and Jarad Mason, together with other co-workers, describe how this works.

"This material is unique in that it binds CO2 in a cooperative mechanism," Long said. "When the first CO2 starts to adsorb at a very specific pressure, all of a sudden it facilitates more CO2 adsorption, and the MOF rapidly saturates. That is really a different property from any other CO2 adsorbent based on amines.

"Then," he added, "if you raise the temperature by applying heat, at some temperature all the CO2 will come flooding off."

Long's team found that the diamines bind to the metal atoms of the MOF and then react with CO2 to form metal-bound ammonium carbamate species that completely line the interior channels of the MOF. At a sufficiently high pressure, one CO2 molecule binding to an amine helps other CO2 molecules bind next door, catalyzing a chain reaction as CO2 polymerizes with diamine like a zipper running down the channel. Increasing the temperature by 50 degrees Celsius makes the reaction reverse just as quickly.

The pressure at which CO2 binds to the amines can be adjusted by changing the metal in the MOF. Long has already shown that some diamine-appended MOFs can bind CO2 at room temperature and CO2 levels as low as 300 parts per million.

The current atmospheric concentration of CO2 is now 400 parts per million (ppm), and policy-makers in many countries hope to reduce this below 350 ppm to avoid the most severe impacts of climate change, from increasingly severe weather events and sea level rise to global average temperature increases of 10 degrees Fahrenheit.

## 'We got lucky'

Last summer, Long co-founded a startup, Mosaic Materials, to use the new technology to radically reduce the cost of chemical separations, with plans in the works for a pilot study of CO2 separation from power plant emissions. This would involve creating columns containing millimeter-size pellets made by compressing a crystalline powder of MOFs.

"We're also hoping to develop something that might be tested in a submarine," Long said. That would pave the way for eventual scale-up to capturing CO2 from natural gas plants, which produce emissions containing about 5 percent CO2, to the higher concentrations of coal-fired power plants.

"We got lucky," he said. "We were just trying to find a simple way to attach these amines to our MOF surface, because they are one of the best compounds for selectively binding CO2 in the presence of water, which can be a problem in flue gas. And it just happens we got the right length in the amine to make these one-dimensional chains that bind CO2 in a cooperative manner."

Long suggested as well that the findings may have relevance for the fixation of CO2 by plants, owing to striking structural similarities between the magnesium-based MOF and the naturally occurring CO2-fixing photosynthetic enzyme RuBisCO.

Long also received assistance from colleagues at Zhejiang University in Hangzhou, China; the University of Turin in Italy; the University of Minnesota in Minneapolis; the Université Grenoble Alpes and the Centre National de la Recherche Scientifique in France; the Norwegian University of Science and Technology in Trondheim, Norway; and the École Polytechnique Fédérale de Lausanne in Switzerland.

The work is supported by grants from ARPA-E and the U.S. Department of Energy-funded Center for Gas Separations Relevant to Clean Energy Technologies, an Energy Frontier Research Center operated jointly by UC Berkeley and LBNL.

### More information

The paper "Cooperative insertion of CO2 in diamine-appended metal-organic frameworks" is published in Nature.

**alchemy.cchem.berkeley.edu**

# Capture and utilisation news

## Callide Oxyfuel Project completes with results

**www.co2crc.com.au**

**The successful collaboration between CO2CRC's Otway Project in Victoria and the Callide Oxyfuel Project in central Queensland has come to the end of a key stage with the completion of the Queensland project.**

The research collaboration between the two projects involved carbon dioxide (CO2) being captured during Callide Oxyfuel trials and transported to the CO2CRC site, where it was subjected to a number of geochemical experiments; experiments that will strengthen knowledge of long term permanent storage. This was the first time in Australia that emissions from an operating power station were captured and stored.

The Otway Project site is ideal for CO2CRC to work with industry as it is representative of conditions likely to be found in real operations. Other research projects being undertaken at CO2CRC's Otway Project site include a high resolution monitoring program which will test and validate existing research and models on the movement of CO2 stored 1,400 metres deep underground; and the design and installation of an adsorption and membrane field facility to test and evaluate CO2CRC's technologies for separation of CO2 during natural gas processing.

CO2CRC's newly appointed Chairman, Mr Martin Ferguson, AM, said "Queensland's Callide Oxyfuel project was a world first demonstration in industrial scale carbon capture technology and CO2CRC's Otway Project is Australia's first carbon dioxide geological storage demonstration site - together these projects have made a significant contribution to the progression of carbon capture and storage (CCS)."

"The Callide Oxyfuel project helped create a pathway for the design and construction of larger scale oxy-combustion plants with carbon capture, and the importance of that contribution should not be underestimated.

"CO2CRC is evaluating the results from the Callide project, and will continue to work with industry to develop CCS as a key technology for large scale emissions reduction." Mr Ferguson added.

## CO2 Solutions announces pilot test results

**www.co2solutions.com**

**CO2 Solutions has announced the results of the pilot testing of CO2 Solutions' carbon capture process, completed in January 2015.**

The results provide support that the Company's technology can provide reduced operating costs and reduced parasitic load relative to conventional CO2 capture processes.

The results indicate that the CO2 Solutions' enzyme-accelerated process, using its proprietary 1T1 enzyme, shows potential for CO2 capture that may be better than existing conventional capture technologies. In addition, CO2 Solutions' technology requires substantially lower temperatures for regeneration than comparable technologies, which would allow for the use of nil-value low-grade heat (<80°C).

"The CO2 Solutions technology is unique in that it can operate using readily available, low-grade heat that would otherwise remain unutilized," stated John Kay, EERC Senior Research Manager. "Using the enzyme-accelerated process from CO2 Solutions, a new economic option is created that has the potential to pave the way for greater adoption of carbon capture for both sequestration and commercial use."

Modelling of CO2 Solutions' technology indicates that by using this low-grade heat, the effective parasitic load on the emitting power plant can be reduced to only 0.2 GJ/tonne of CO2 captured. Parasitic load is a measure for the reduction in efficiency of power generation plants as a result of bolt-on carbon capture processes and is the largest operating cost component of these same processes.

The Company's technology compares very favourably with the 3.5 GJ/tonne parasitic load for conventional amine-based (MEA) technology, or even with recent announcements regarding claims of approximately 2.2 GJ/tonne from more advanced amine-based solvents. Implementation of such technologies with high parasitic loads would result in a significant increase in the cost of power generated as well as a reduction in the net generating capacity of the power plant.

The testing programme was conducted at the facilities of the EERC, who led the performance evaluation of CO2 Solutions' process. The test data was then used as inputs for models to simulate CO2 capture from typical coal- and gas-fired power generation plants, based on the methodology established by the U.S. Department of Energy (DOE), in order to provide meaningful benchmarking.

"These conclusive results position our technology well for larger-scale demonstration, such as our project with Husky Energy," stated Dr. Louis Fradette, CO2 Solutions' Chief Technology Officer. "We thank the EERC for their collaboration during the test program and look forward to working with them again in the near future".

The results were based on testing of CO2 Solutions' enzyme-accelerated process, applied to flue gas from natural gas and coal combustion. The testing involved the use of EERC's state-of-the-art packed column test facility at a scale of approximately 1 tonne-CO2/day. Using CO2 Solutions' proprietary high performance 1T1 enzyme, the concluded programme represents the largest scale test to date of an enzyme-based CO2 capture process.

As a follow up to today's announcement, CO2 Solutions and EERC will present the results with further details at the 14th Annual Conference on Carbon Capture Utilization & Sequestration in Pittsburgh, PA on April 29, 2014.

## CO2 Solutions receives $400k Government loan

**www.co2solutions.com**

The repayable loan will be used to optimize the company's carbon capture technology.

CO2 Solutions has received a $400,000 commitment from Canada Economic Development for Quebec Regions (CED) towards optimization of the Corporation's carbon capture process and new enzyme production at industrial scale.

The CED assistance has been awarded in the form of a $400,000 repayable financial contribution through CED's Quebec Economic Development Program. Under the terms of the contribution agreement, CO2 Solutions will apply these funds toward the continued development of specific elements of the Corporation's innovative carbon capture process.

CO2 Solutions will be required to refund the contribution over a period of 60 monthly payments.

## CRI and MHPSE ally on power to methanol with CO2 capture

**www.eu.mhps.com**

Carbon Recycling International (CRI) and Mitsubishi Hitachi Power Systems Europe (MHPSE) have formed a strategic alliance to deliver power-to-methanol solutions to increase operation efficiency of coal power and chemical plants.

Methanol is in high demand as a basic chemical and fuel for transport. Power-to-methanol is a viable technology for large-scale storage of wind and solar power.

The companies will market and deliver CRI's power-to-methanol technology, (Emissions to Liquid -ETL) and MHPSE's expertise in the integration of thermal power systems and environmental engineering equipment to enable power plants to operate at economic capacity levels, even when large variations in demand and supply are imposed by intermittent electricity from renewable sources on the grid.

The companies will also provide energy upgrade solutions to chemical manufacturers for hydrogen recovery and carbon dioxide capture from flue gas to produce low carbon intensity methanol.

CRI is the first company to demonstrate industrial solutions in power-to-methanol production, by capturing carbon dioxide (CO2) from power plant flue gas, by developing large-scale conversion of renewable energy to hydrogen, and by reacting hydrogen and carbon dioxide to produce methanol. CRI's power-to-methanol production plant in Iceland, which has been operating since 2012, produces ultra-low carbon intensity methanol that is used for biodiesel manufacturing and gasoline blending. The plant has recently been expanded to 4000-t/year production capacity.

A joint demonstration of load-following operation of power-to-methanol technology with a power plant will be demonstrated in the ongoing EU research project MefCO2 [Grant Agreement No. 637016] at the power plant in Lünen, Germany. Full commissioning and operation at Lünen is scheduled in 2017.

Meanwhile, in even shorter term, other installations in industry can be realized economically at full commercial scale. Examples include iron and steel mills, which can realize significant carbon reduction in primary steel production with simultaneous methanol production.

MHPSE has both extensive know-how and a longstanding track record in the design and construction of high efficiency power-generation systems as well as integration of environmental engineering systems in modern power plants. Many of the largest thermal power plants in Europe have been spearheaded by MHPSE.

"This alliance allows Carbon Recycling International to gain the ability to market and deliver its power-to-methanol equipment and systems to clients in the power industry and chemical sector across Europe," remarked KC Tran, CEO and co-founder of CRI. "Mitsubishi Hitachi Power Systems Europe has been a leader for many decades in the design and construction of thermal power plants in Europe and their team brings unique capability and understanding of the needs of power systems operators during the important transition from fossil fuels to renewable energy."

# Transport and storage news

## U.S. DOE projects store 10M tonnes of CO2

**energy.gov**

**In a landmark accomplishment, the U.S. Department of Energy has announced that a group of carbon capture and storage projects supported by the Department have safely captured 10 million metric tons of carbon dioxide.**

One DOE supported project alone has now captured nearly 2 million metric tons of CO2. Air Products and Chemicals, Inc. in Port Arthur, Texas, is demonstrating a state-of-the-art system to capture carbon emissions from two steam methane reformers used to produce hydrogen. Air Products retrofitted its steam methane reformers with an advanced system that separates CO2 from the process gas stream. The CO2, in compressed form, is then delivered by pipeline to enhanced oil recovery projects in eastern Texas.

"The U.S. is taking the lead in showing the world CCS can work. We have made the largest government investment in carbon capture and storage of any nation, and these investments are being matched by private capital," said Energy Secretary Ernest Moniz. "We are showing that CCS is working now, and that it is indispensable to the DOE's commitment to reduce greenhouse gas emissions and tackle climate change."

The projects contributing to the 10 million tons captured milestone are part of DOE's Regional Carbon Sequestration Partnership (RCSP) Initiative and the Industrial Carbon Capture and Storage (ICCS) Major Demonstrations programs.

The RCSP Initiative consists of seven partnerships focused on determining the best regional approaches for storing CO2 in geologic formations. The Partnerships include more than 400 organizations spanning 43 states and four Canadian provinces, and form the core of a nationwide network to identify optimal technologies, geologic carbon storage sites, regulatory options and infrastructure requirements to ensure the safe storage of CO2 and facilitate the commercial deployment of CCS.

The ICCS program – representing a $1.4 billion investment under the American Recovery and Reinvestment Act – is a major step forward in the effort to reduce CO2 emissions from industrial plants. The program has helped industry demonstrate the CCS technologies that can be readily replicated and commercially deployed in industrial facilities.

## Indiana University geochemists model underground movement of stored CO2

**www.iu.edu**

**Computer modeling by geochemists at Indiana University and colleagues in China and Sweden has shown more detail of the fate of CO2 stored underground.**

The research, published in the International Journal of Greenhouse Gas Control, demonstrates a close match to the actual movement of a carbon dioxide plume over nearly 20 years at the Sleipner carbon capture and storage project off the coast of Norway.

Chen Zhu, professor in the Department of Geological Sciences in the College of Arts and Sciences at IU Bloomington and lead author of the article, said the model should apply to similar underground storage systems elsewhere, including carbon capture and storage projects that could be built in the U.S. Midwest.

"We are reasonably confident we can predict the fate of the CO2, where it will end up after a number of years," he said.

Co-authors of the article are IU doctoral student Guanru Zhang, former IU doctoral student and postdoctoral researcher Peng Lu, Lifeng Meng of Zhejiang University in China and Xiaoyan Ji of Lulea University of Technology in Sweden.

Zhu and his colleagues used a computer model that simulates factors that could influence the way the gas moves underground, including pressure, temperature, spill rates, permeability of the geologic formation and other factors.

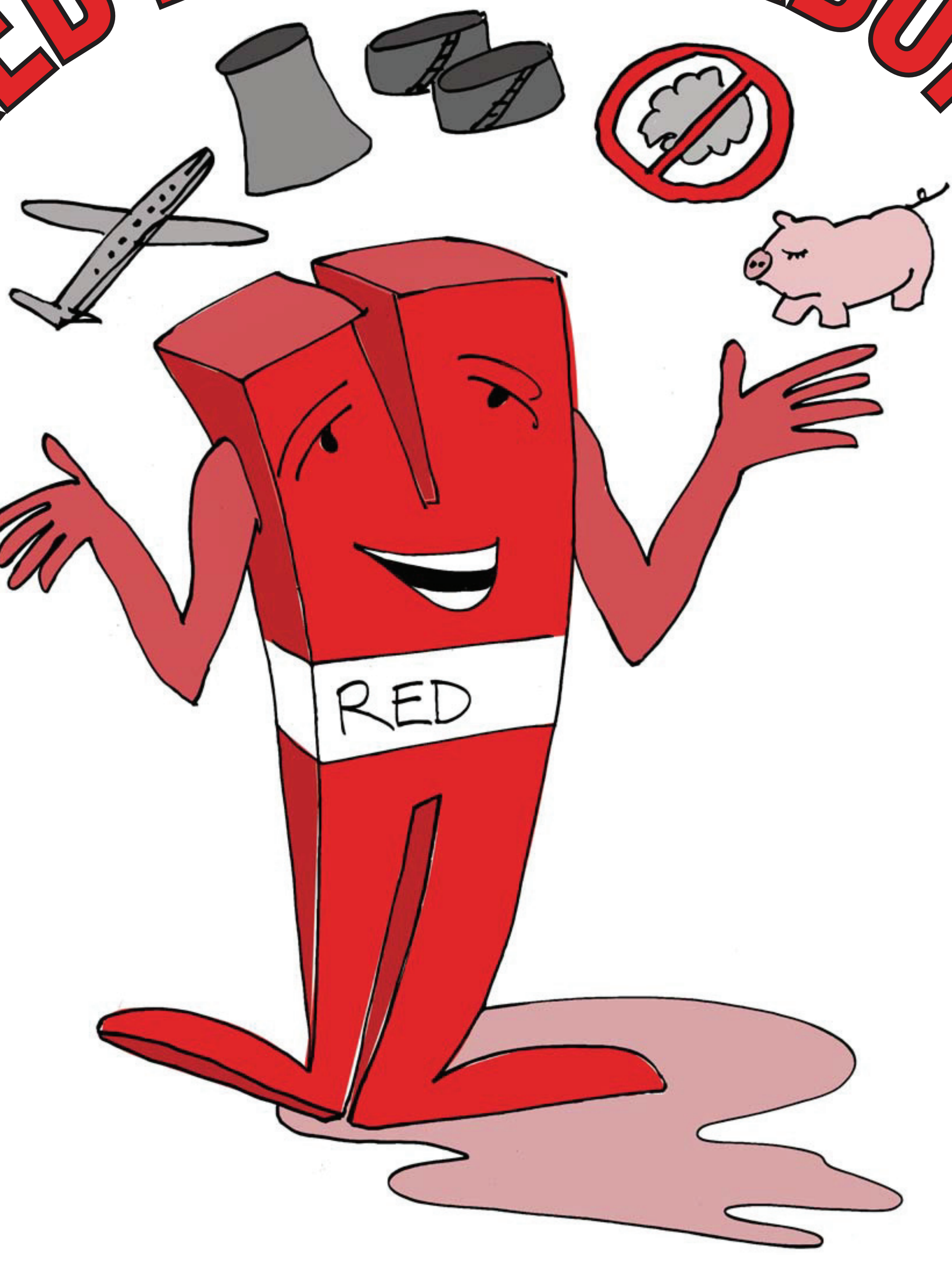
Through approximately 200 simulations, aided by IU's new powerful supercomputer Big Red II, they concluded that permeability, temperature and impurities were factors that contributed to the shape of the plume at the Sleipner project. Applying the model to future carbon capture and storage projects in other parts of the world, Zhu said, could help government regulatory agencies decide whether such projects should be authorized.

Statoil, a Norwegian oil and gas company, opened the Sleipner Project in 1996 in response to a carbon emissions tax that the nation adopted five years earlier. The first commercial CO2 storage project in the world, the project stores about 1 million tons of in the brine-filled Utsira sandstone formation about a half-mile beneath the Norwegian North Sea.

Zhu studied carbon dioxide capture and storage at the Sleipner site in the 2008-09 academic year as part of the Fulbright Scholar Program. The Sleipner project has included seismic mapping and extensive data collection over 20 years, he said, allowing the creation of a model that matches real-world conditions.

The article, "Benchmark modeling of the Sleipner CO2 plume: Calibration to seismic data for the uppermost layer and model sensitivity analysis," is available online. Funding for the research came from the U.S. Department of Energy and the Norwegian Center of Excellence in Subsurface CO2 Storage.

# RED HYDROCARBON

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