Carbon Capture Journal

CCS in Asia

China's strategy to offset CCUS costs through CO2 utilisation

Japan's renewed interest in coal power + CCS after Fukushima

Nov / Dec 2014 Issue 42

SaskPower Boundary Dam begins operation with Shell Cansolv technology

- Solidia and Linde collaborate on CO2 curing for concrete
- Recycling power plant emissions into fuel with algae
- Copper foam that turns CO2 into useful chemicals
- Carbon capture 'slurry' developed that combines solid and liquid

New test era at Technology Centre Mongstad

CO2 Technology Centre Mongstad in Norway has already contributed to a series of advancements in reducing the cost and the technical, environmental and financial risks of implementing CO2 capture technology.

The two successful technology demonstrations of Aker and Alstom are complete and the sophisticated test centre is ready to receive new vendors.

With the commencement of the Cansolv testing in September, TCM is entering a new phase of testing.

Cansolv's test campaign will be performed using exhaust gas from the Combined Heat and Power Plant at Mongstad, with focus on process verification and emission control.

TCM is the world's largest and most advanced facility for testing and improving CO2 capture, and is a joint venture set up by the Norwegian state (75.12 %), Statoil (20 %), Shell (2.44 %) and Sasol (2.44 %).

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Front cover: The world's first large scale post-combustion coal fired carbon capture and sequestration project has begun operation at SaskPower's Boundary Dam Power Station in Estevan, Saskatchewan. Among other services, Shell Cansolv provided the CO2 stripper (pictured)

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Leaders - CCS in Asia & SaskPower Boundary Dam

Special section on CO2 utilisation

Projects and policy

Capture and utilisation

Transport and storage

CO2 utilisation technology, China's key to develop CCUS

China is looking to CO2 utilisation technologies to offset the costs of carbon capture and storage and possibly provide a revenue to further its implementation.
By Xiaoliang Yang, Research Analyst, World Resources Institute

China, the world's largest CO2 emitter, has been showing increasing interest in tackling climate change, including develop/deploy Carbon Capture, Utilisation, and Storage (CCUS) technology. As an emerging climate change technology for deep reduction of CO2 emissions from fossil-fuel consumption, China's climate change and energy policy cycle has attached great importance to CCUS.

CCUS is the only way for China to continue using coal without increasing its CO2 emissions. At present, Coal still accounts for 70 percent of China's total electricity generation capacity. The Global CCS Institute considers China as the most active nation pursuing CCUS technology with strong government support and investment from China's powerful state-owned energy enterprises.

Since 2006, 16 Ministries in China issued more than 10 national policies and guidelines to encourage exploration of CCUS technologies. Just in 2013, five policy guidelines related to CCUS were issued. Major ones included National Development and Reform Commission's Notice on Promoting CCUS Pilot & Demonstration Projects, Ministry of Science and Technology's the Special Program for CCUS Technologies within the 12th Five-Year Plan, and Ministry of Environmental Protection's Guideline to Strengthen Environmental Protection on CCUS Pilot & Demonstration Projects.

China's Huaneng Group, Shenhua Group, SINOPEC are all moving their CCUS demonstrate project in a concrete way. In spite of this progress, major hurdles are still keeping China from demonstrating/deploying large-scale CCUS projects, such as the high energy penalty and high cost, technology feasibility and risk management.

Without appropriately addressing these challenges, China's CCUS development might never enter the next stage of technology innovation: five to ten large-scale CCUS demonstration projects.

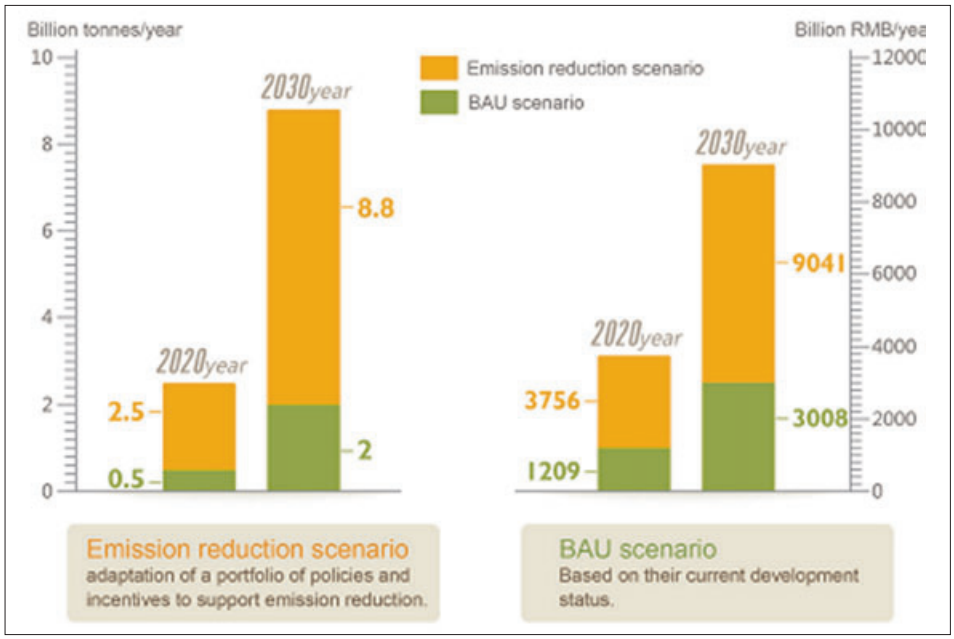

Figure 1 - The potential of emissions reduction of CO2 utilisation in China under two scenarios (Source: China's National CO2 Utilisation Technology Assessment Report, ACCA21)

China's First National CO2 Utilisation Technology Assessment Report

China's policy makers have turned to CO2 utilisation technologies for solutions, even though some major multi-national agencies downplay the role of CO2 utilisation technology in the CCUS chain. Clearly, China's energy and climate change pundits do not agree with that.

In China, environmental and economic benefits are equally important for any clean energy technology. Moreover, it is attractive that CO2 utilisation technologies can offset the high cost of carbon capture; by integrating low-cost CO2 capture sources, the CCUS chain might make extra profits and eventually, help the country more easily implement the technology.

Based on this rationale, the Administrative Center of China's Agenda 21, an agency of the Ministry of Science and Technology, published China's First National CO2 Utilisation Technology Assessment Report in April 2014, as the Third National Climate Change Assessment Report's Special Issue. More than 30 of China's national experts joined in this study for more than one year, examining more than 25 CO2 utilisation technologies (Table 1) through its technological development stage, CO2 reduction potential and economic feasibility.

Key Findings

Main findings show that CCU technologies have a great potential to achieve deep CO2

reductions and considerable economic benefits. It is worth presenting the results under two scenarios, Business as Usual and Increasing Support from Government.

Business-as-Usual

Under this circumstance, government will not provide special support; and industry will develop the technology based on market needs. As a result, it is estimated that CCU technologies will not play a significant role in emissions reduction until 2030.

By 2020, CO2 utilisation demonstration projects can reduce CO2 by 50 million tons/year (0.8% of the 2011 total CO2 emissions); By 2030, most CO2 utilisation technologies will achieve commercialization, with an annual CO2 reduction of 200 million tons/year (3% of the 2011 total CO2 emissions).

Geological Utilization	Chemical Utilization	Biological Utilization
CO2-Enhanced Oil Recovery	CO2-Biodegradable Polymer	Algae to Biofuel or Chemicals
CO2-Enhanced Coal Bed Methane Production	CO2-Isocyanate/Polyurethane	Algae to Fertilizer
CO2-Enhanced Gas Recovery	CO2-Policarbonate/Polyester	Algae to Food/Feed Additives
CO2-Enhanced Shale Gas Recovery	CO2-Vinyl Polyester	Gas Fertilizer
CO2-Enhanced Geothermal Systems	CO2-Poly Butyl Diacid Glycol Ester	
CO2-Enhanced Uranium Leaching	CO2-to-Liquids	
CO2-Enhanced Water Recovery	CO2-Methanol through Hydrogenation	
	CO2-Dimethyl Carbonate	
	CO2-Formic Acid	

Table 1 - 25 CO2 Utilisation Technologies

China's government adopts aggressive policy support

The research group also calculated the CO2 emissions reduction based on strengthened government policy support and private investment. Under this scenario, China's governments will significantly support the R&D of CO2 utilisation technology (as well as CCUS as a whole) and create a more enabling market environment. I

n this case, more than 20 CO2 utilisation projects will be able to achieve commercialization by 2020 with CO2 emissions reduction of 250 million tons/year (4% of the 2011 total CO2 emissions). By 2030, major CCU technologies will be commercialized, with CO2 emissions reduction of 880 million tons/year (13% of the 2011 total CO2 emissions).

Early Opportunities

One of the key research tasks of this study is to identify where China can actually start its large-scale CCUS full-chain demonstration projects, called "early opportunities" by Chinese CCUS pundits.

Early opportunities must have low-cost of CO2 sources, low transport cost, and be utilized for profits (Figure 2). In addition, early opportunities must be easily integrated to China's existing industry and energy structure. As the world's largest energy consumer, China has massive CO2 emissions sources, including coal power plants, iron and steel industry, cement industry, and coal chemical industry.

Many of these industries can provide low-cost captured CO2 given its high-concentration in flue gas, like the coal-to-chemicals industry, cement industry, and steel industry. Furthermore, if these industries are located in or nearby coal basins or oil fields, the transport cost can be low and CO2 utilisation is possible.

Based on this thinking, the research group identified a few CCUS combinations in different geographic regions in China.

• The cluster of thermal power generation, CO2-EOR, and other CO2 geological utilisation in Jungar Basin, Ordos Basin, Tu-ha Basin

• The cluster of coal chemical industry, CO2-ECBM, CO2 chemical utilisation technology in Ordos Basin, Jungar Basin, Hailer Basin

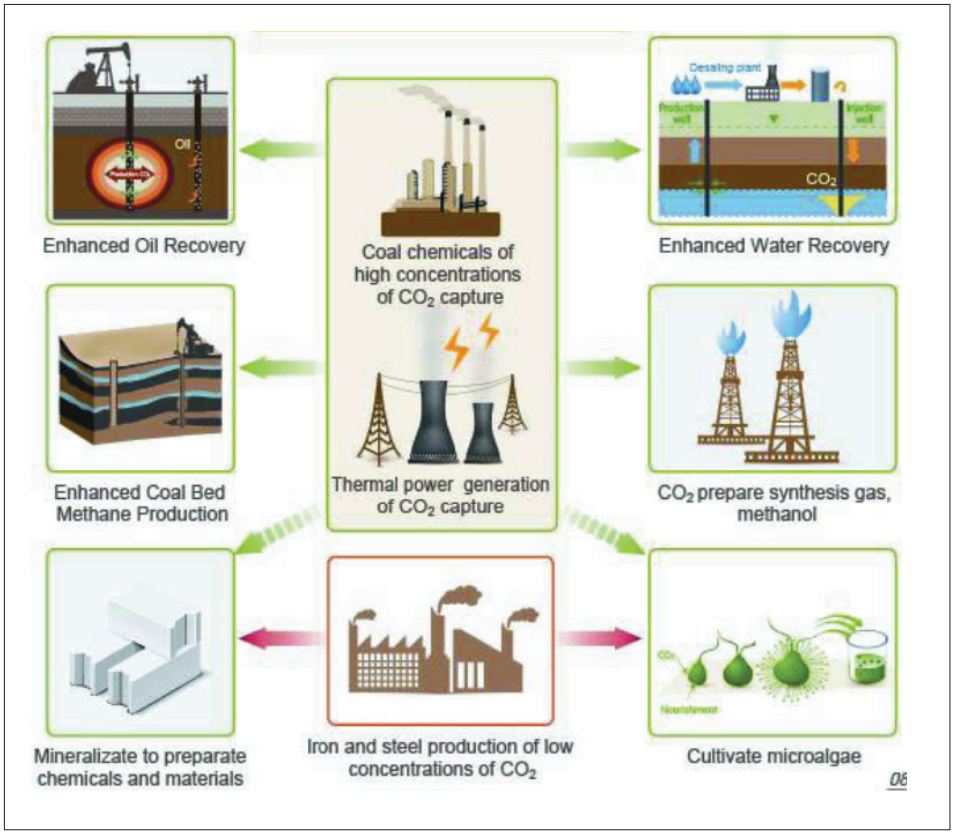

Figure 2 - Early opportunities without geographical and industrial restrictions

• The cluster of Iron and Steel production, mineralization, microalgae in the field of agriculture, chemicals, renewable energy, etc.

Final Thoughts

CCUS is essential for China to continue using coal to fuel its economy and to meet its climate change goals. As CCUS is losing momentum in many other parts of the world, China is still rapidly advancing CCUS by investing resources from both government and industry. However, no country has yet figured out how to move CCUS forward to achieve its climate change goals given its high cost, energy penalty, uncertain technological feasibility, lack of project experience, etc.

Learning-by-doing in China through some early opportunities in the next few years now looks very critical to achieving the commercialization of CCUS around 2030. China's massive CO2 emission sources do provide a good environment for this learning-by-doing activity, in particular, China's rapidly growing coal-to-chemicals industries.

In Xinjiang Province, around hundred domestic and international corporations are now constructing more than 60 coal mines and coal-to-chemicals plants with a huge capital investment. If the country cannot deal with CO2 emissions from this emerging industry, it can be a disaster for China's future climate change policy.

China's central government should encourage (or even require) the project owners to develop CCUS projects with the exploration of CCUS opportunities. China is making its 13th 5 year economic development plan now; and certainly, CCUS will be included in the emissions control plan. Regardless, China's economic development and energy structure and CCUS technology are inseparable from each other.

More information

Further Reading: China's National CO2 Utilisation Technology Assessment Report, The Administrative Center of China's Agenda 21, 2014 (in Chinese)

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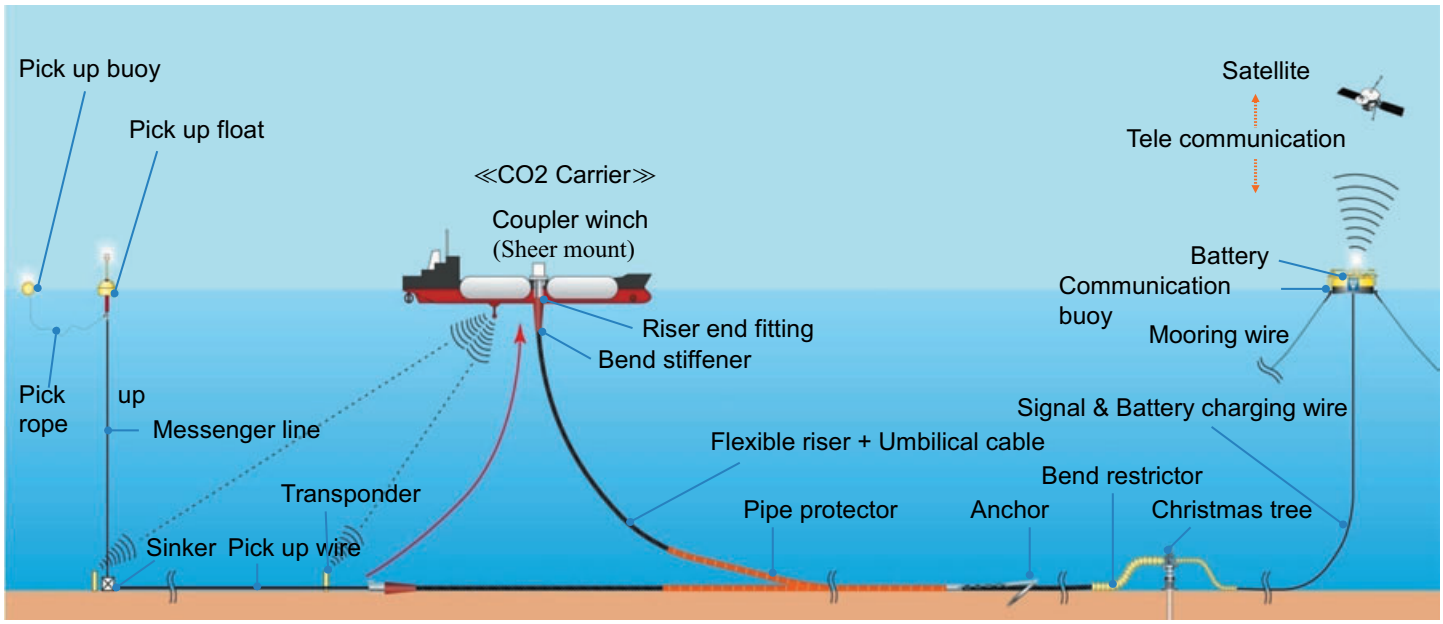
Advancing Japan's energy post Fukushima

With the shutting down of all nuclear power facilities after the Fukushima incident, Japan has turned back to conventional power plants for its energy needs and CCS is receiving renewed attention as a key technology to reduce carbon emissions.

By Terufumi Kawasaki



The Shuttle Ship Initiative, promoted with Global CCS Institute's members in Japan

Securing a staple electricity supply to support Japan's social and industrial needs has been a critical issue since the 2011 nuclear accident in Fukushima. Since the accident, all nuclear power stations have been shut down, with existing thermal power stations making up for the shortfall. The shutdown facilities, which once powered approximately 50GW, include 54 units along with Fukushima Daiichi station. Many aging power facilities have been restarted, exposing Japan to large shortfalls due to low efficiency and high running costs.

This year, power companies began invitations for tenders for new thermal power facilities which are approximately 10GW in total capacity. The increase of thermal power plants, however, brings up another serious issue: how to cope with combatting global warming.

That is why carbon capture and storage (CCS) is receiving more attention nowadays together with the discussion on carbon dioxide (CO2) emission reduction.

Resources and energy measures

Japan's Ministry of Economy, Trade and Industry (METI) plans for it to be 'the world's most advanced country in terms of energy' by diversifying energy sources. In particular it plans to significantly increase renewable energy and achieve higher efficiency in coal-fired power generation. An important theme is the development and accelerated application of highly efficient thermal power generation and in that context, the implementation of CCS is mentioned.

A FY2014 budget of Yen11.3 billion is comparable to the FY2013 budget level (Yen12.6 billion), which shows the willingness of METI to continuously invest in the advancement of CCS. Moreover, as a diplomatic strategy contributing to the global greenhouse gas (GHG) emission reduction, METI also included the cost of the Joint Crediting Mechanism (formally called Bilateral Credit Mechanism) through which Japan can diffuse its own advanced technologies in partner countries.

CCS to help reduce GHG emissions by 80 %

Earlier this year, the Ministry of Environment (MOE) called for the need to accelerate the advancement of CCS in order to help reduce Japan's GHG emissions by 80% by 2050. It drew up a new Yen1.25 billion plan to tackle this task. According to the plan, MOE will carry out exploration of suitable CO2 storage sites in the surrounding waters including offshore areas. It also considers the transportation system necessary for CO2 storage, planning demonstration testing which is expected to start in three years.

As Japan consists of mountainous islands, there is not much free space onshore, with its coastal areas highly developed for many dif-

ferent uses. For that reason, tapping into surrounding waters including offshore areas could help accelerate the CCS implementation in Japan.

Shuttle Ship Initiative on CCS

The plan to identify CO2 storage sites in Japan will help determine the viability of the CO2 transportation system to offshore storage sites by ships. This concept originated as a two-year Global CCS Institute project in 2011 with the research team led by Professor Ozaki of Tokyo University, developed in collaboration with Global CCS Institute's Japanese Members such as Chiyoda Corporation. The Japanese Government is now actively supporting this plan. This is one example of the Japan-Australia cooperation facilitated by Global CCS Institute.

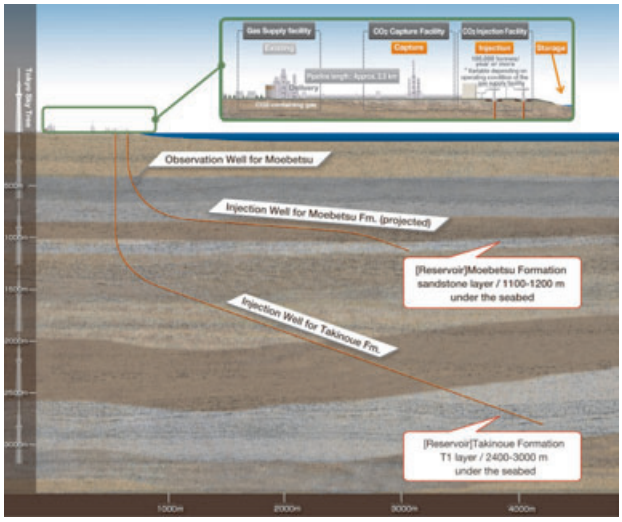
In contrast to Europe's conceptual transportation system using ships to carry CO2 to offshore facilities, Japan has developed an alternative system which sends relatively small shuttle ships back and forth between power stations (CO2 capture plants) along the coast and offshore storage sites. By installing injection equipment on shuttle ships, offshore facilities at the storage sites would not be necessary.

The concept uses small tankers (3,000 ton), enabling CO2 storage tanks at power stations to be down-sized. These developments could make this system highly extendable, allowing flexible applications for multiple capture and storage sites at low costs. Setting up a number of offshore storage site expands the potential of CO2 storage, making CCS a viable option in other countries as well.

Technology Shift from Energy-Saving to CCS in Industries

Japanese companies have long contributed to CO2 emission reduction through the development of advanced energy saving technologies. In addition, since late 20th century they have invested in the development of technologies relating to CCS in cooperation with the Japanese government and utilities. Engineering companies first started CCS-related works in Japan, followed by electric-machinery ones. The two segments of industry have developed CCS technologies in their business fields which are oil and gas and power generation, respectively.

In late 1970s, after the oil crisis, the world's oil and gas industry began to adopt the technology of enhanced oil recovery (EOR) including a profitable method of CO2 injection. Japanese engineering companies also followed the business, starting to develop the technologies for capture, transportation, and injection of CO2. Japan, however, had such a small number of domestic oil and gas fields that these companies gained much of their experience and advanced CCS-related technologies through their projects overseas.



Japan's first large-scale CCS project, the "Tomakomai Project" with 100,000 tons of CO2 injection per annum is funded by the government and operated by Japan CCS Co., Ltd.

In 1990s, the UN initiated the world movement of combatting global warming, and Japan's utilities and steel companies began to consider the reduction of CO2 emission, investing in research and development of CO2 capture technologies for their facilities. More recently in the mid 2010s, Japanese companies continue to develop CCS-related technologies for commercialisation.

> CCS in Japan can be summarised with three key terms: 'Highly-efficient thermal (especially coal-fired) power generation'

Japan's CCS suppliers

JGC Corporation, Chiyoda Corporation and Toyo Engineering Corporation are examples of engineering companies experienced in supplying CO2 capture, transport and storage technologies in the oil and gas business. In addition, they have applied the CO2 capture technologies to industrial field (for example: chemical fertilizer plants).

Electric-machinery companies, putting focus on CO2 capture technologies, are MHI, IHI, Toshiba and so forth. They have successfully developed the capture technologies for coal-fired and gas-fired power stations with their own funds and/or in collaboration with power companies.

To do this, they undertook a process to investigate various methods such as pressure/temperature swing adsorption, chemical absorption, and oxyfuel combustion, through which they obtained abundant data on pros and cons of the technologies. Besides, Nippon Steel & Sumikin Engineering is developing a unique technology that captures CO2 from blast furnace gas for the application to steel industry.

Projects involving Japanese companies

Japan's first large-scale CCS project (so-called "Tomakomai Project" with 100,000 tons of CO2 injection per annum) is funded by the government and operated by a special purpose company, Japan CCS Co., Ltd., consisting of utilities and others. JGC Corporation is in charge of capturing CO2 from a hydrogen production process of an oil refinery facility. The company was engaged in the In Salah CCS project in Algeria with engineering expertise.

Another Japanese CCS initiative which aims to transport CO2 by shuttle ship to store under sea-beds off shore, is mainly engaged by Chiyoda Corporation. In another example of an oil mining project overseas, Toyo Engineering Corporation completed a CCS facility (approximately one million tons of CO2 per annum) in Brazil last year, which is cited as Lula Oil Field CCS Project in the Global Status of CCS 2013 issued by the Global CCS institute. The equipment produced is featured by two excellent technologies; a membrane CO2 separation technology under high pressure and the world's highest compression system (50MPa) able to inject CO2 to much deeper layers.

CCS for thermal power plants

CCS Projects for thermal power plants are strongly invested in by Japanese companies. A test facility for capturing CO2 from coal-fired power plants is operated by Toshiba, which built the facility (chemical absorption method; 10t/day) on its affiliated company power station site. The electric-machinery company has developed different and unique technologies (under atmospheric pressure) from those amongst the engineering companies.

Another test plant for a pre-combustion process is operated by J-POWER, which made the equipment with two types of processes (chemical absorption and physical adsorption; 24t/day) in its IGCC demonstration plant site.

Large-scale projects overseas utilise other Japanese electric-machinery companies; MHI took part in Southern Company's CO2 capture facility (chemical absorption, 500t/day) in U.S. and is engaged in Petro Nova Project which is a commercial CCS+EOR project with a coal-fired power plant (chemical absorption, 4800t/day) in U.S.; IHI is involved in Callide project (oxy-fuel combustion, 70t/day) in Australia. Each company has actively invested in the development of CCS-related and distinguishing technology and acquired operational experiences, which would lead it to the level of commercialisation as high as that of Alstom and Shell.

Research institute to promote CCS technology development

In order to understand what is going on for CCS-related R&D in Japan, it would be helpful to learn about Research Institute of Innovative Technology for the Earth (RITE), which is a foundation (total contribution: Yen9.9 billion) established in 1990 as the central research institute to develop innovative environmental technologies, with funds from the government and related governmental organizations.

Its research facility is located on the outskirts of Kyoto City, made famous by the Kyoto Protocol. RITE has approximately 160 researchers and is operated with an annual project budget of around Yen2.4 billion (FY2013). Recognising that CCS is an essential climate mitigation measure to achieve the 2 Degree scenario (2DS), RITE proactively promotes CCS technology development.

Research Topics

Research topics for RITE include the assessment of global warming mitigation scenarios and R&D on CCS and bio-refineries. As for the CCS-related technologies, the institute sets a special focus on the development of chemical solvents, solid absorbent materials and CO2 separation membranes that lower the cost of CO2 capture technologies, thereby promoting commercialisation. In the field of storage, the institute has been developing various technologies including geological modeling, simulation technologies to be applied for aquifers, monitoring with optical fibers.

RITE implemented an experiment injecting 10,400 tons of CO2 into aquifers in the areas along the Sea of Japan in mid-2000s, using the data to develop the Japan specific geological model, which is still being updated.

Since October 2013, RITE and a steel company have been working on the commercialisation of a system using chemical solvents. This system captures CO2 in blast furnace gas from steel plants to be used at liquefied CO2 plants, and is said to have obtained the world's top-class performance of 2.0GJ/tonne-CO2.

Contribution to International Standardisation for CCS

RITE is also working to promote the international standardization of CCS under the framework of ISO (ISO/TC265).

The institute has been representing Japan as the secretariat of the Japanese mirror committee of ISO/TC265 since 2011. In February 2013, Japan was selected as conveners for both Capture and Storage Working Groups. The international standardisation of CCS will institutionally promote and aid the commercialisation of CCS.

Japan's Perspectives for world-wide deployment of CCS

CCS in Japan can be summarised with three key terms. 'Highly-efficient thermal (especially coal-fired) power generation', in which Japan is a proud world leader. It is hoped it will provide the country with a stable supply of electricity at low cost, and when accompanied by a carbon capture facility, reducing carbon emissions to near zero.

This advancement is highly possible as Japanese companies have developed and demonstrated the technology for decades as along with environmental purification technologies such as desulphurization and denoxzation. The total energy output minus loss of capturing carbon dioxide could be still maintained to a high level, making the combined technology good news for many developing countries that do not have sufficient energy resources.

Shuttle Ship Initiative', - providing Japan with the option of offshore storage sites negating the difficulties of gaining public acceptance for onshore sites. This is also good news for countries that do not have EOR sites.

'Bilateral Offset Credit Mechanism', proposed as a practical way of knowledge sharing between advanced and developing countries, and could accelerate cooperative deployments of CCS in the world. We would have to solve the different way of thinking on the issue between the two groups in the world.The way Japan has taken and the hardship it has recently undergone could help make an important role for combatting global warming.

Acknowledgement

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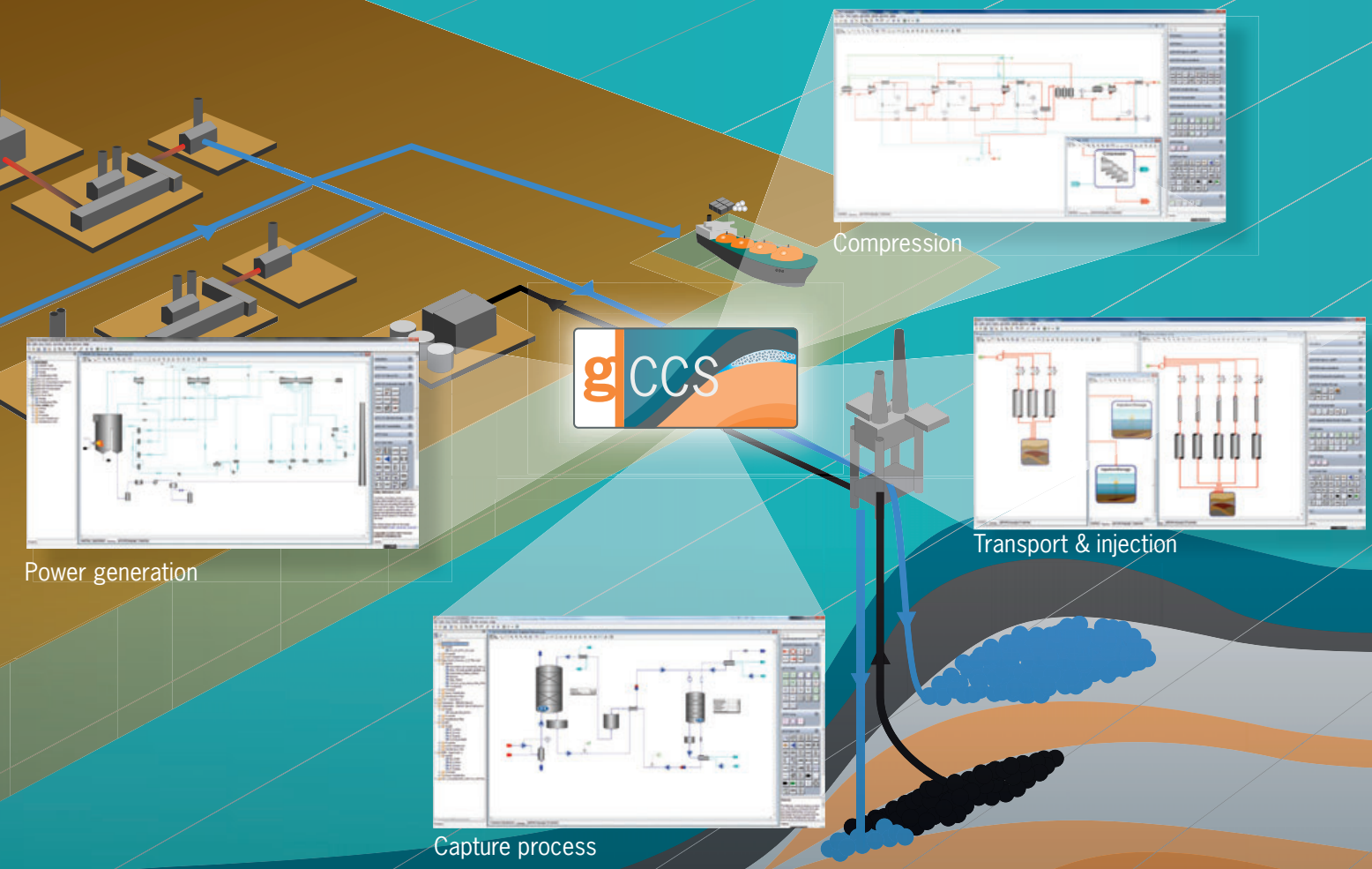

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Shell Cansolv in the SaskPower Boundary Dam ICCS Project

The start-up of the SaskPower Boundary Dam Integrated Carbon Capture and Storage (ICCS) Demonstration Project is a major milestone for the fossil fuel power industry worldwide, as it demonstrates the viability of large scale CO2 capture. This article will focus on Shell Cansolv's contribution to this project along with a brief description of major challenges and lessons learned.
By Karl Stéphenne, Shell Cansolv

In October 2014, the world's first large scale post-combustion coal fired carbon capture and sequestration project began operation at SaskPower's Boundary Dam Power Station in Estevan, Saskatchewan. Above and beyond being the process licensor, technology provider and amine supplier for both the flue gas desulphurization and CO2 capture processes, Shell Cansolv has provided a multitude of products and services to SaskPower for this first-of-a-kind achievement.

Shell Cansolv's contribution spanned from the supply of modular amine filtration and amine purification units to overall process performance optimization, going through operator training, support of plant commissioning & start-up and review of standard operating procedures. This project is a milestone for the fossil fuel power industry worldwide, as it will prove the viability of large scale CO2 capture and demonstrate that carbon capture can be brought successfully to commercial scale.

A milestone for the fossil fuel power industry worldwide

Saskatchewan relies heavily on coal for electrical power and is affected by federal emission regulations. With one of the fastest-growing economies in Canada, Saskatchewan is a strong supporter of the development of CCS because the province's circumstances mean the technology can provide significant economic and environmental benefits.

The SaskPower Boundary Dam Integrated Carbon Capture and Storage (ICCS) Demonstration Project is a major milestone for the fossil fuel power industry worldwide, as it demonstrates the viability of large scale CO2 capture. This article will focus on Shell Cansolv's contribution to this project along with a brief description of major challenges and lessons learned.

Extending the useful life

Unit 3 of the Boundary Dam Power Station was an aging asset in the SaskPower fleet and was subject to the new federal regulations on the reduction of CO2 emissions from coal-fired power plants. According to the current projections, the upgrades to the unit will extend its useful power production life by 30 years.

At full capacity, the SaskPower ICCS Demonstration Project captures over one million metric tons of CO2 per year, reflecting a 90% CO2 capture rate for the 150 MW coal fired unit. The resulting captured CO2 emissions are compressed and transported through pipelines to Cenovus Energy who uses the CO2 for Enhanced Oil Recovery (EOR) activities in the Weyburn oil field. Weyburn is recognized as the largest geological CO2 storage project in the world. Meanwhile, all the SO2 present in the flue gas is recovered and used for production of sulphuric acid which is subsequently sold as a valuable by-product.

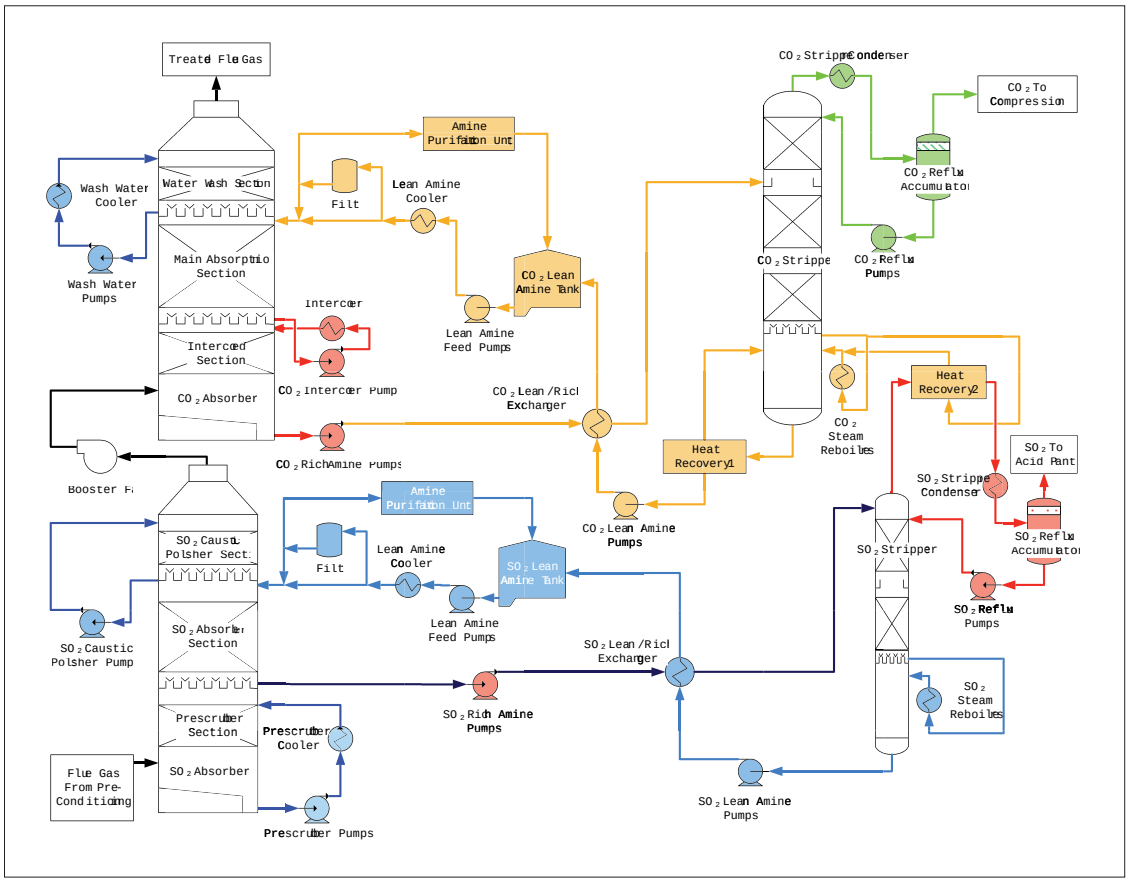


Figure 1: Cansolv process line-up for the SaskPower BD3 CCS Project

The innovative combined SO2/CO2 capture system

The Cansolv process line-up for the SaskPower Boundary Dam ICCS Project, presented in Figure 1, includes a particular design enhancement: selective heat integration with Shell Cansolv's innovative combined SO2/CO2 capture system helps to reduce energy requirements associated with carbon capture. With this approach, the Capture Plant steam requirement is significantly reduced.

"As the first large scale project of its kind in the world, this is a huge step forward in validating that our technology is enabling an economical benefit while providing a profitable EOR development", states Luc Camiré, Director of Engineering at Shell Cansolv. "The use of Shell Cansolv's technology will enable SaskPower to meet the growing demand for sustainable and affordable low carbon-intense electricity."

The Shell Cansolv contribution

Shell Cansolv, a subsidiary of Shell Global Solutions, is a world leader in the design and development of regenerable amine based gas scrubbing technologies. Shell Cansolv offers solutions for the control of atmospheric pollution through high efficiency post combustion removal of SO2 and CO2 in a wide range of industrial applications.

Coal fired power plants represent the largest single point emitters of anthropogenic CO2. Depending on the origin of the coal, SO2 emissions can be as high as 3,000 ppmv SO2. Shell Cansolv has developed a technology that targets the combined capture of SO2 and CO2 from such applications, exploiting opportunities for integration and further reducing energy requirements. This breakthrough technology sets a new paradigm for amine-based scrubbing technologies operating in oxidative environments.

The contribution of Shell Cansolv to SaskPower Boundary Dam ICCS Project is quite diverse. Above and beyond being the process licensor, technology provider and amine supplier for both the flue gas desulphurization and CO2 capture processes, Shell Cansolv is providing a multitude of products and services to SaskPower. For example, Shell Cansolv:

1) Supplied modular amine filtration and amine purification units;

2) Reviewed detailed engineering documents and vendor drawings;

3) Developed and reviewed training material and provided training to the operators;

4) Helped environmental permitting efforts by conducting thorough biodegradability, tox-

icity and ecotoxicity tests;

5) Managed evaluations to identify the best available waste water treatment technologies;

6) Advised and supported organization, preparation and execution of commissioning and start-up;

7) Helped prepare and register safety data sheets used for operation and maintenance;

8) Reviewed standard operating procedures;

9) Provides specialized support of experts from the wider Shell organization;

10) Supported successful start-up through specific project assurance activities;

11) Provides ongoing counsel to optimize overall process performance before and after the warranty test.

Winter Challenges

Amongst some of challenges encountered during engineering, construction, commissioning & start-up of this first-of-a-kind project, one major hurdle came from the harsh climate of Saskatchewan. The initial project schedule minimized any crucial construction and commissioning activities taking place in winter. However, because the final investment decision was delayed by 6 months the schedule was shifted, resulting in some critical construction steps falling in the dead of winter.

To erect the acid resistant brick lined concrete absorbers, cold climate and falling snow reduced the scheduled window when concrete could be poured. A special heated shelter, using recycled ethylene glycol as the source of radiant heat, erected on a hydro-mobile system to raise it to elevation, was used to reduce the construction schedule of the concrete absorbers. Looking back, starting field construction in late winter would have maximized concrete pours at elevation during warmer periods.

Upon first hydrostatic loading of the concrete absorber and lean amine tank, specific temperature ranges had to be respected. In the middle of winter, this required special equipment to pre-warm the concrete structure with warm air and caused additional delays.

Other challenges included the achievement of a "zero liquid leak" chimney tray objective. While the design had been enhanced, the actual fabrication quality was the main challenge. After multiple tests and repairs sessions in a very confined area, the weld quality finally met specifications and virtually no leaks were detected under both static and circulation mode.

The CO2 stripper supplied by Shell Cansolv

Conclusion

Through innovation and determination, Shell Cansolv and SaskPower have succeeded in demonstrating that CO2 capture on this scale is not only possible but realistic as well. This first adoption of commercial scale CO2 capture sets the stage for the global fossil fuel industry. The learnings gained from this project will serve to advance adoption of CCS and will help to reduce costs on subsequent projects.

More information

www.cansolv.com

www.saskpowerccs.com

CO2-curing technology for concrete

Solidia Technologies is collaborating with Linde on a new CO2-curing technology that could untap the potential value of CO2 as a commodity for pre-cast concrete production.

By Dr. Nick DeCristofaro, Chief Technology Officer, Solidia Technologies, and Dr. Andreas Opfermann, Head of Clean Energy and Innovation Management, Linde

The two companies are working to reduce the industry footprint of concrete and re-categorize CO2 as a catalyst for profitability and growth.

U.S. start-up Solidia Technologies® has joined forces with The Linde Group, a world-leading supplier of industrial gas and equipment and engineering company, to industrialize an innovative technology that could reduce the environmental footprint of pre-cast concrete while reducing production costs and improving the performance of building materials. The collaboration will include the development, demonstration and commercialization of Solidia's carbon dioxide (CO2)-based concrete curing technology. The two companies are also collaborating on marketing the technology as a new solution for the pre-cast concrete sector.

Concrete is the most widely used material in the world. The cement industry, which provides ordinary Portland cement (OPC) to the concrete industry, is the second largest emitter of carbon dioxide in the world, responsible for three to five percent of total global carbon emissions. Six of the top 10 traders in carbon credits in Europe are cement companies. Cement manufacturers have committed to reducing their carbon footprint but are often constrained by their assets and chemistry.

Solidia's CO2-based concrete curing technology utilizes Solidia Cement™ , a novel chemistry developed by Solidia. The patented technology allows lower CO2 emissions in the cement production process and involves the use of CO2 in precast concrete manufacturing. Overall, CO2 emissions associated with the production and use of cement can be reduced by up to 70 percent. Benefits include superior concrete product performance, reduced materials and water usage as well as shorter curing times.

By helping develop a means of transforming CO2 into a valuable commodity for one of the world's largest industries, the Linde-Solidia collaboration will help speed the market penetration and social impact, re-categorizing CO2 as a catalyst for profitability and growth.

The Cement Sustainability Initiative of the World Business Council for Sustainable Development set 2050 CO2 reduction targets for the global cement industry. Hypothetically, if the industry were to adopt Solidia's technologies today, it could achieve those 2050 goals within three years.

Solidia Concrete blocks (above), hollow-core slab (next page left), and railroad sleepers (next page right)

Novel CO2-curing Technology

Solidia Concrete™, a new, sustainable concrete that consumes carbon dioxide in the curing process, is defined by both its proprietary curing process and its formulation—a blend of water, coarse and fine aggregate, and Solidia Cement.[1] Solidia Concrete can be adapted easily by manufacturers of conventional concretes.

Solidia Cement, a requisite ingredient in the formulation of Solidia Concrete products, is composed primarily of low-lime containing calcium silicate phases. The curing of concrete products made using Solidia Cement is derived from a reaction between these low-lime calcium silicate phases and gaseous carbon dioxide (CO2) in the presence of moisture. During the carbonation curing process, calcite (CaCO3) and silica gel (SiO2) are formed and are responsible for the development of strength within the concrete. This is in contrast to the hydration process that occurs in Portland cement-based concrete, which involves the hydration reaction between high-lime calcium silicate phases and water to form calcium-silicate-hydrate gel and calcium hydroxide.

The curing process of concrete made using Solidia Cement sequesters up to 300 kg of CO2 per tonne[2] of cement. When the reduced CO2 emissions associated with Solidia Cement production are considered along with the ability of that cement to sequester CO2 during concrete curing, the CO2 footprint associated with the manufacturing and use of cement can be reduced by up to 70% compared to OPC.

Solidia Concrete can be produced by manufacturers of traditional concretes and can be designed to address any precast concrete application. These products, which include paving stones, concrete blocks, hollow-core slabs, railroad sleepers (ties), roof tiles, and

1. Solidia Concrete and Solidia Cement are interdependent materials; Solidia Concrete can only be made with Solidia Cement. All calculations herein are based on trials using Solidia's patented processes. See the two-part white paper series, Solidia Concrete™, published February 2014, and Solidia Cement™, published December 2013.

2. All calculations are based on the tonne, also known as the metric ton, equaling 1,000 kilograms.

pervious concrete, match or exceed the properties and characteristics of concrete products made using OPC. Additionally, the Solidia Concrete curing process can be completed in a matter of hours, allowing for rapid deployment. As water is not consumed during the Solidia Concrete curing process, it can be collected and reused, with recycle rates in excess of 60 percent, and potentially as high as 100 percent.[3]

Solidia Concrete Microstructure

To create Solidia Concrete products, water, aggregates and Solidia Cement are mixed, formed into the desired shape and then reacted with gaseous CO2 to produce a hardened structure. During the carbonation reaction, calcium is dissolved from the surface of each cement particle, reacts with CO2 in the capillary pore space, and precipitates as calcite on the outer surface of the particle. Simultaneously, an insoluble layer of silica gel forms within the outer boundary of the cement particle, maintaining the original contour of the particle. The cores of some cement particles remain unreacted, while others are completely reacted, leaving only silica gel surrounded by calcite.

The calcite and silica gel reaction products occupy ~62% more solid volume than the Solidia Cement reactant. This volume expansion takes place entirely within the capillary pore space and does not cause any volume expansion of the concrete product. Unlike Portland cement, which continues to react in the presence of water, Solidia Cement curing stops once the concrete is removed from the CO2-curing environment.

The calcite acts as a binding phase within the Solidia Cement paste and is similar in function to the C-S-H gel in Portland cement paste. The silica gel has nanometer size pores, which are similar to the gel pores of C-S-H in the Portland cement paste.

Delivering and managing CO2

A critical development along the path to commercializing Solidia's technologies will be managing and delivering CO2 to the concrete curing. Supply of CO2 will be first for in-plant pre-cast and eventually for on-site cast-in-place construction. Linde will bring CO2 supply and delivery expertise, including engineering of application-specific equipment, to contribute to this joint development. With its impressive fleet of CO2 trucks, railcars, ships for CO2 transport, its experience with CO2 production, and its wide range of applications-specific knowledge, Linde is well prepared to support the roll-out of this technology. This project marks an important step in proving and enhancing Linde's CO2 management capabilities.

Introducing innovation to an old, traditional industry is a tall order. Solidia is bringing a sustainable innovation to a market that dates back 2,000 years and whose last major product innovation was the invention of Portland cement in the early nineteenth century. Solidia is tasked not only with the development of sustainable technologies, but making those technologies easy for industry to adopt.

Creating a sustainable pathway for the cement and concrete industry requires the development of new, affordable technologies that will not overburden the industry with capital investments or dramatic changes in production. By marrying the scientific innovation of a start-up with the market intelligence, engineering and construction capabilities and global infrastructure of established industry leaders, Solidia and Linde are accelerating the drive to a future where sustainability will immediately conjure forecasts of profitability.

As collaborators with a global reach and decades of technological and market knowledge, industry leaders such as Linde play a significant role in driving innovation to market. Linde's expertise in gas delivery and equipment engineering enables rapid commercialization by freeing Solidia to focus on the development of the core technology. Likewise, Solidia's technology gives Linde access to a large, new market for CO2 that would not exist without Solidia.

R&D Funding from US DOE National Energy Technology Laboratory

This fall, Solidia renewed a research and development project co-funded by the US Department of Energy's National Energy Technology Laboratory (NETL). To date, the ongoing research project has been funded with US$1.1 million from the NETL through its Carbon Storage Technology program and US$1 million from Solidia Technologies as cost share. The research focus includes the water use, CO2-curing time, and mechanical strength of Solidia Cement-based concrete.

NETL supports Solidia Cement-based concrete technology because of its potential to consume CO2 as it cures, which falls within NETL's mission to support the development of technologies that reduce or avoid man-made greenhouse gases emitted to the atmosphere. NETL implements a broad spectrum of energy and environmental research and development (R&D) programs exploring commercially viable solutions to national energy and environmental problems.

The focus of the NETL funded research at

3. See white paper, Water Savings in Concrete Made from Solidia Cement™, published April 2014.

Solidia has, most recently, included the understanding of water distribution in concrete during the drying and curing process and how that water distribution can be controlled to allow concrete curing in the shortest period of time.

The research demonstrated that Solidia Concrete can achieve full hardness in less time than traditional concrete made from Portland cement. In every application studied, Solidia Concrete cures in less than 24 hours as compared to the curing time of 28 days required for OPC-based concrete to achieve full hardness. In addition, at every stage of curing, Solidia Concrete parts match or exceed the strength of comparable products made with OPC-based concrete.

The research findings further demonstrate that, when the reduced CO2 emissions associated with Solidia Cement production are combined with the CO2 reacted into Solidia Concrete, the CO2 footprint of precast concrete products can be reduced by up to 70 percent.

"As an alternative building material with a lower carbon footprint, Solidia Cement is an excellent example of the innovative technologies DOE's Carbon Storage Program advances in its mission to promote solutions for reducing CO2 emissions", stated NETL Carbon Storage Technology Manager Traci Rodosta. "We're hopeful that the commercial success of Solidia Cement will encourage the view that CO2 has untapped value as a commodity."

NETL recently agreed to finance the project's next stage, which will focus on demonstrating this CO2 reduction and storage capability on a prototype scale in a commercial concrete plant.

Collaborators Committed to Commercializing Sustainable Solutions

The Linde collaboration and NETL research funding add to a robust roster of collaborative testing agreements and third-party research that reinforces Solidia's technology and product development. Solidia purposefully seeks partnerships with private and public sector leaders committed to commercializing sustainable technologies. Prominent among these is ongoing research in cement production and concrete applications with Lafarge, who signed a partnership agreement with Solidia in October 2013.

A world leader in building materials, Lafarge employs 65,000 people in 64 countries and boasts the world's leading building materials research facility. Lafarge places innovation at the heart of its priorities in order to contribute to more sustainable construction and to better serve architectural creativity.

Since 2010, the Lafarge Group has been part of the Dow Jones Sustainability World Index, the first global sustainability benchmark in recognition of its sustainable development actions. As part of the agreement, Lafarge conducted trials with Solidia to demonstrate feasibility of commercial-scale cement production in the first half of 2014. The two companies are actively collaborating to market this technology as a new solution for the pre-cast sector.

During a panel discussion on "Integrating Innovation into Industry," that took place in April during a conference at the University of Virginia, Peter Quail, vice president, Precast Concrete of Lafarge's Innovation Division, commented on the sustainability features of Solidia Cement: "As a 35-year veteran in the precast concrete industry, I see the physical characteristics and properties of this material to be a real game changer. Not only will Solidia cement result in an improved product with higher profitability for the precast concrete customer, it also represents a new paradigm with respect to sustainability."

Other collaborators include the U.S. Department of Transportation's Federal Highway Administration supports Solidia with a Cooperative Research and Development Agreement (CRADA) to examine transportation infrastructure applications at the Turner-Fairbank Highway Research Center. Long-term research continues at Rutgers, the State University of N.J., where the original generation of the technology was developed, while collaborative concrete characterization research efforts are underway in laboratories at Purdue University, Ohio University, and the University of South Florida.

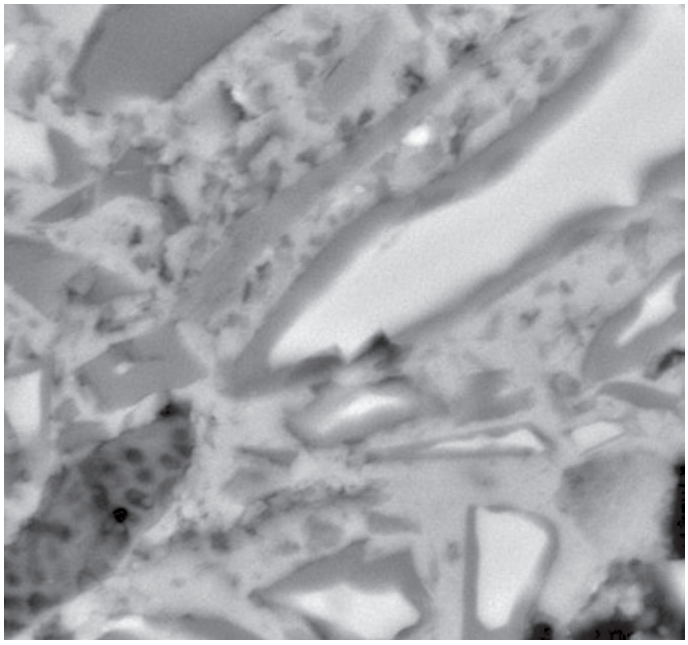


Figure 1. SEM-BSE image showing the microstructure of Solidia Cement paste area of a concrete sample

Conclusion

Solidia's CO2-curing technology offers concrete manufacturers significant cost savings compared to water-based curing of conventional cement based products, plus faster curing times, lower energy usage, reduced raw material consumption and waste generation, and reduced labour requirements.

Creating a sustainable pathway for the cement and concrete industry requires the development of new, affordable technologies that will not overburden the industry with capital investments or dramatic changes in production. The partnerships between Solidia, Linde, Lafarge, US government agencies and university laboratories marry the scientific innovation of a start-up with the market intelligence and global infrastructure of established industry leaders, and the expertise, facilities and funding available in the public and academic sectors. Together, this integrated team is accelerating the drive to a future where sustainability will immediately conjure forecasts of profitability in the cement and concrete industries.

More information

www.solidiatech.com
www.linde.com
www.lafarge.com

Recycling power plant emissions into fuel using algae

MasseReaction has developed an algae technology that can capture CO2 and other pollutants from power plant emissions and convert them into sustainable drop-in fuels for transportation. The resulting fuels are cheaper than fossil fuels in the open market.

The company is now seeking a strategic partnership and raising funds through crowdsourcing to build a pilot demonstrator.

Virtual view from the interior of a ViPAR farm building with tens of thousands of stacked modules

The concept is called ViPAR™ (Vertically integrated Photo Array Reactor) and involves a vertically stacked array of growth tubes where algae can live in optimum conditions. Because of its vertical arrangement, the system can be scaled up while maintaining a small footprint.

The industrial scale of capture capability realized in ViPAR, allows for significant levels of fuel production; enough to not only offset cost, but sufficient to create sustainable profitability, the company believes.

The idea originated with an airline captain in the U.S.A., Arthur WP Massé. who wanted to find a natural solution to the problem of rising oil prices and fuel supply. The result is a carbon capture and recycling system that uses algae to convert CO2 into lipids which can be converted into fuels.

"Algae provide the natural process of making stored energy by synthesizing oil from solar energy," explained Mr. Massé. "Conceptually, I realised that due to land use requirements, any successful algae cultivation system must be extremely efficient and employ a vertical farming method."

"After much research, I discovered that there was absolutely nothing like this device that had ever been patented, even though it was simple in its concept. I began to learn how to write a patent application, and eventually engaged a brilliant professional to finalize the claims. Remarkably, we have never been required to defend a single claim in any patent office anywhere in the world. We are very pleased with the solid scientific foundation upon which ViPAR is built."

"We have been fortunate to benefit from the knowledge and insight of some world-class engineers and scientists who have assisted us with technical details and process refinements such as those given us by Algal Production and Optimization LLC, with whom we have contracted for lipid enhancement technology."

About the technology

ViPAR is capable of adding energy to existing CO2 via natural photosynthesis. By implementing a hybrid artificial/solar lighting system, the company expects to increase energy augmentation levels well above the 50% achievable using only an artificial lighting system.

"The inherent characteristics of ViPAR CO2 capture make it highly efficient at industrial volumes. In comparison with other algal systems, ViPAR requires only 50 acres (20 hectares) of land footprint versus the 210 square miles of open ponds required to capture the CO2 from an average US coal fired power plant," said Mr. Massé.

A 50-acre ViPAR installation includes processing facilities, fuel storage tank farm, multi-modal transportation terminals, parking, office, and green space.

Annual drop-in renewable ViPAR fuel production is a total of 600 million US gallons (2.25 billion litres) from a single 667MW power plant. The breakdown is roughly 100 million gallons (375 million litres) of drop-in renewable diesel, 100 million gallons (375 million litres) of drop-in renewable jet fuel, and 400 million gallons (1.5 billion litres) of non-food sourced ethanol..

Using historic average fuel spot market pricing models, reduced by approximately 10%, ViPAR fuels are predicted to produce a 45% return on investment at a full-scale (667 MW) facility. In turn, the larger the facility, the higher the efficiency of operation. ViPAR Fuels are capable of maintaining competitive pricing through high levels of market price volatility.

How it works

ViPAR is a module containing thousands of growth tubes. These modules can be stacked in an array to heights of up to approximately 15 metres. The tubes of each module align perfectly with the tubes of the modules adjoining above and below, effectively creating thousands of reactor tubes, 15 meters high.

Each module receives light via fiber optic transmission lines, and each tube in the module receives light via optical pathways. Each tube radiates 'cold' light toward its centre via holographic optical devices present in the tube walls. This patented feature of ViPART allows precise control of temperatures inside each reactor tube, while delivering precise frequency and intensity of light to each and every algae cell growing in the reactor - a perfect algal growth environment.

"This is a giant leap forward in photobioreactor technology," explained Mr. Massé. "Artificial lighting, placed in close proximity to the reactor tubes, has generally been utilized to achieve required intensities of light inside the reactor tubes. High intensity artificial light sources placed close to the reactor result in elevated levels of radiated, and consequently trapped, heat. This heating effect can cause thermal runaway. Unregulated environmental temperatures place stress on the organisms, and left unchecked, can kill the algae."

> ViPAR fuel production can provide a revenue stream that more than offsets costs

Tens of thousands of these reactor modules can be stacked into thousands of arrays and placed indoors. A 'stressed skin' fabric building made by a company called Sprung Structures, which is inexpensive to construct, fast to erect, and can be insulated is the first line of environmental controls that keep UV light out, giving a confined space in which to precisely regulate temperature, as well as a clean environment that can be protected against hostile windborne particles It is designed to resist wind load up to 125 mph (200 km/h), as well as to shed snow and ice.

MasseReaction will also employ an algae environmental manipulation and control system that will allow it to multiply the production numbers of algae as well as the lipid (oil) content the algae produce.

This will allow 'local' algae to be used instead of genetically modified algae. MasseReaction will use the common algae growing at each location a ViPAR installation is built. The algae will be given ideal conditions under which they can multiply and grow.

With ViPAR, the CO2 uptake process gains efficiency with increasing volume; the same is true for the harvesting and separation processes.

"MasseReaction has taken a divergent track from the 'norms' of harvesting and processing algal oils and sugars, which traditionally involve centrifugation, drying and pressing algae to capture the oil product. MasseReaction will employ multiple stages of hydrodynamic 'motive flow' and ultra-sonic processing to split cell walls and achieve isolation and separation of algal components."

Sugars will be distilled into ethanol via distillation, and oil will be processed into ViPAR Fuels, which are drop-in renewable diesel and jet fuels produced via Fisher-Tropsch. Both processes produce CO2 that is again captured and returned to the ViPAR farm for use by algae.

Application and environmental impact

By producing drop-in renewable liquid transportation fuels, ViPAR replaces much of the petroleum based toxins and GHG's that would be released to the atmosphere from the production, import, and refining of fossil based fuels. "The technology provides the fuels production capacity to make any developed country independent from foreign fuel imports," said Mr. Massé.

MasseReaction sees ViPAR as a technology that can help countries dependent on coal for electric power generation. Coal is a cheap and abundant primary fuel source for emerging and developed countries alike. By recycling CO2 via algae photosynthesis, GHG and atmospheric heavy metals will be effectively reduced by the amounts of fossil fuels that are displaced by ViPAR fuels.

"Deployed across the United States fleet of gas and coal fired power plants, ViPAR could remove 1.6 billion tons of CO2 emissions from the atmosphere; representing approximately 16% of the world's annual total."

Future plans

The current challenge is initial funding for the technology, as it is a capital intense endeavour. MasseReaction estimates the cost of a commercial demonstrator to fall in the $50 million range with a sustainable profitability topping 20 million annually

MasseReaction believes that as soon as a technology demonstrator shows the verified CO2 uptake and fuel production capabilities of ViPAR, that funding for a fully sustainable commercial demonstrator could be easily acquired through an investment-banking consortium or through private financing.

"When you consider that many large fuel consuming companies spend tens of millions of dollars hedging fuel costs every quarter, it is a very attractive risk vs reward scenario," said Mr. Massé.

"We are actively seeking a Strategic Partner interested in moving ViPAR technology forward with us. We are can help Strategic Partners with Carbon Credits and expansion of their revenue base, if they are a power producer; or, if they are a large single point fuel consumer like an airline, a maritime shipping company, or rail line, we would be willing to offer them long term fixed fuel pricing such as open market 'spot' minus 10% with a 21 day fixed price component."

MasseReaction says it has a deployment plan that can cover the globe in 20 years; enough time to possibly slow global warming.

"Potential algal products are myriad. Most algae producers have abandoned fuels and are making higher value products like pharmaceuticals, nutraceuticals, and cosmetics in attempt to break even and make a profit. We have chosen fuel as a primary product not only because of its critical nature to national economy, but as a proof of ViPAR efficiency.

"We see a lot of opportunity ranging from renewable lubricants to plastics. Once you have the carbon chain, it becomes a question of how many molecules you want in that chain in order to make the products you wish to develop. We are excited about the possibilities that we can cultivate through R&D."

More information

www.massereaction.com

Copper foam turns CO2 into useful chemicals

Scientists at Brown University's Center for Capture and Conversion of CO2 have discovered that copper foam could provide a new way of converting excess CO2 into useful industrial chemicals, including formic acid. The research is published in the journal ACS Catalysis.

A catalyst made from a foamy form of copper has vastly different electrochemical properties from catalysts made with smooth copper in reactions involving carbon dioxide, a new study shows.

As levels of carbon dioxide in the atmosphere continue to rise, researchers are looking for ways to make use of it. One approach is to capture CO2 emitted from power plants and other facilities and use it as a carbon source to make industrial chemicals, most of which are currently made from fossil fuels. The problem is that CO2 is extremely stable, and reducing it to a reactive and useful form isn't easy.

"Copper has been studied for a long time as an electrocatalyst for CO2 reduction, and it's the only metal shown to be able to reduce CO2 to useful hydrocarbons," said Tayhas Palmore, professor of engineering and senior author of the new research. "There was some indication that if you roughen the surface of planar copper, it would create more active sites for reactions with CO2."

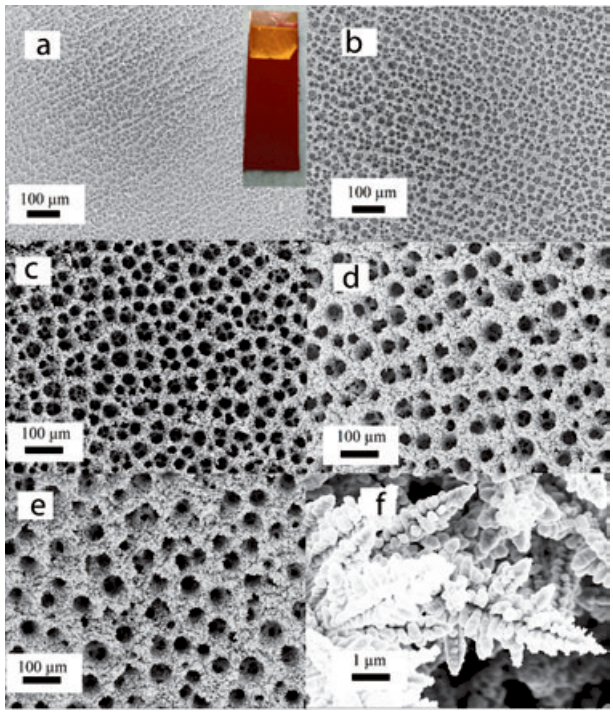
Copper foam, which has been developed only in the last few years, provided the surface roughness that Palmore and her colleagues were looking for. The foams are made by depositing copper on a surface in the presence of hydrogen and a strong electric current. Hydrogen bubbles cause the copper to be deposited in an arrangement of sponge-like pores and channels of varying sizes.

After depositing copper foams on an electrode, the researchers set up experiments to see what kinds of products would be produced in an electrochemical reaction with CO2 in water. The experiments were performed by Sujat Sen and Dan Liu, graduate students in chemistry working in Palmore's lab at Brown's School of Engineering.

The experiments showed that the copper foam converted CO2 into formic acid, a compound often used as a feedstock for microbes that produce biofuels, at a much greater efficiency than planar copper. The reaction also produced small amounts of propylene, a useful hydrocarbon that's never been reported before in reactions involving copper.

"The product distribution was unique and very different from what had been reported with planar electrodes, which was a surprise," Palmore said. "We've identified another parameter to consider in the electroreduction of CO2. It's not just the kind of metal that's responsible for the direction this chemistry goes, but also the architecture of the catalyst."

Now that it's clear that architecture matters, Palmore and her colleagues are working to see what happens when that architecture is tweaked. It's likely, she says, that pores of different depths or diameters will produce different compounds from a CO2 feedstock. Ultimately, it might be possible to tune the copper foam toward a specific desired compound.



A foam of copper Copper is the only metal that can reduce CO2 to useful hydrocarbons. A foam of copper offers sponge-like pores and channels, providing more active sites for CO2 reactions than a simple surface. Image: Palmore lab/Brown University

Palmore said she's amazed by the fact that there's still more to be learned about copper.

"People have studied electrocatalysis with copper for a couple decades now," she said. "It's remarkable that we can still make alterations to it that affect what's produced."

The work in the study is part of a larger effort by Brown's Center for the Capture and Conversion of CO2. The Center, funded by the National Science Foundation, is exploring a variety of catalysts that can convert CO2 into usable forms of carbon.

"The goal is to find ways to produce some of the world's largest-volume chemicals from a sustainable carbon source that the Earth not only has in excess but urgently needs to reduce," said Palmore, who leads the center. "This is a way for us as scientists to begin thinking of how we produce industrial chemicals in more sustainable ways and control costs at the same time. The cost of commodity chemicals is going nowhere but up as long as production is dependent on fossil fuels."

More information

The Center for Capture and Conversion of CO2 is a Center for Chemical Innovation funded by the National Science Foundation (CHE-1240020).

www.brown.edu

Rank hydrocarbons 'black' or 'green'

Dr Rex Gaisford, a former Exec VP and MD of Hess International and founder and past chairman of the UK North Sea "CRINE" initiative of the 1990s ("Cost Reduction in the New Era"), has come up with an interesting way to solve the climate issue and in the process make carbon capture financially viable. This is all achieved by labelling all hydrocarbons either 'black' or 'green' and letting the market resolve the price.

The world, or initially parts of it (such as the EU or the US) would adopt an allowable CO2 emissions plan which in accordance with scientific evidence, would agree how much CO2 could be emitted to the atmosphere every year. This allowable level must start with today's levels but then gradually decrease to a sustainable level over a period of [say 20] years.

Purchasers of Hydrocarbons would be classified on the basis of the end use as Green or Black (or somewhere in between). Green end-users would be those who emit zero CO2 and Black end-users would be those who emit 100% CO2. Shades of Green could be adopted as a sophistication.

Hydrocarbon producers (i.e. oil, gas and coal companies) could sell (Green) Hydrocarbons of any type and any quantity on an unrestricted basis to suitably qualified and certified emitters. The end use emitter would determine whether the Hydrocarbon being sold was Green or Black.

Hydrocarbon producers could sell (Black) Hydrocarbons freely on the market but only to the extent that the total amount of CO2 that would arise from such global sales in a given period such as a year, if combusted would remain within the allowable CO2 emissions plan.

Clearly the market price for Green as against Black will develop along different trajectories and both will be competing with all other forms of energy production such a renewables. However, the only way that Hydrocarbons can prosper will be by investment in removal or re-sequestration of the carbon by such mechanisms as CCS. Then the market can take care of the rest.

A global agreement for this is as unlikely as a global agreement over any type of carbon emissions, but this scheme could be implemented on a regional basis. For example, the European Union could agree on how much 'black' hydrocarbons it wishes to import or produce, and any hydrocarbons beyond this would need to be certified 'green'.

At first sight, the system may sound a bit like the carbon trading scheme, but is in fact very different and is much simpler, on the basis that there are a lot less E&P companies to regulate, Dr Gaisford says. The carbon trading scheme relies on regulating every CO2 emitter in the world, and detailed agreements with the government of every country which emits CO2.

Dr Gaisford argues that the carbon emissions trading scheme is in fact too complicated to work, and does not produce any incentive to invest in CO2 reduction until the imposition of carbon pricing on all existing emitters reaches the critical tipping point at which point the world cost of energy has been increased by 50 – 100% before any incentivised investment in CO2 reduction has even started.

Also, with so many opportunities for get-out clauses, large amounts of money paid for credits and no-one knows where it goes (rather than money being spent on actually reducing emissions), and a requirement for governments to get the perfect amount of control over the market – too much control and it ceases to be a market, too little control and the price drops to nothing.

But this alternative system would only require just regulating the Green and Black markets, whilst the petroleum and coal producing companies would be regulated by the markets themselves. It might be hard to sign up every single oil, gas and coal producer, and the new markets and their regulators, to participate, but with a smaller number of participators, it would be easier.

There is no real difference between regulating CO2 emissions and regulating hydrocarbon production, in that all produced hydrocarbons will ultimately be burned and released CO2. The question for policy makers and industry to answer is, given that we need to regulate CO2 emissions, is it easier to do that by directly regulating emissions, or regulating the hydrocarbon production through a controlled market?

Dr. Gaisford says, that "there is a fundamental principle in play here": to achieve any universally agreed reduction in global CO2 emissions by any method or policy whatsoever, global production of hydrocarbons (HCs) will be similarly reduced, unless the CO2 arising from it is sequestered.

The guiding principles of the scheme therefore are:

- Reduce total energy consumption throughout the world economy by continuously reducing overall global energy demand. Do this despite world population growth and emancipation, by erecting commercial incentives on a global scale through promotion and subsidies. Incentives paid for by the OECD countries.
- Steadily reduce global allowable anthropogenic CO2 emissions on a declining trajectory (to 2035?) in accordance with world scientific evidence/agreement.
- Allow (Black) Hydrocarbon to compete normally in the Hydrocarbon market to the extent only that its carbon content is at or below the allowable anthropogenic CO2 emissions' carbon content downward trajectory.
- Allow (Green) Hydrocarbon to compete normally in the energy market alongside (Black) Hydrocarbon and Cfree energy.
- Set up and nurture genuine market competition between Cfree energy (renewables etc.) and the new Hydrocarbon markets (Black & Green) to meet an agreed political timetable (by 2035?).
- Encourage Hydrocarbon E&P Countries and Hydrocarbon companies on a global scale for their own business interests, to commercially invest in re-sequestration of CO2 (e.g. CCS or re-forestation.)

If the whole world commits to such a process, the outcome will be:

- Energy use both per capita and eventually overall, will fall
- Free-burn (Black)HC extraction/production will shrink
- Cfree and Reseq energy volumes will grow steadily
- Energy will become much more expensive but the world will adjust.

IEA report - developments in oxyfuel combustion of coal

A report from the International Energy Agency reviews technological progress in each element of the oxyfuel plant, as well as presenting the latest results from large pilot projects and demonstration Front-End Engineering Design (FEED) studies. It also looks at recent analyses of the potential efficiency and economic performance of future commercial-scale plant are compared.

In the last five years, oxyfuel combustion has benefitted from successful full-chain pilot tests to cement its status amongst the viable options for CCS with coal plant, says the report, by Toby Lockwood at the IEA Clean Coal Centre.

The technology is now widely considered to be ready for scale-up to a demonstration phase in which its suitability for commercial deployment can be assessed by the operation of a large-scale oxyfuel plant. While no major technological barriers have been encountered in developing oxyfuel to the scale of large pilot plants, the scope for research has only continued to grow as efforts have focussed on further optimisation of plant performance and new means of reducing the efficiency penalty imposed by the capture process.

Drawing on both lab-based and pilot-scale tests, considerable research experience has now been acquired in the altered behaviour of coal combustion in an atmosphere of oxygen and recycled flue gases. Whilst the destabilising effect of the increased heat capacity can in large part be countered by raising oxygen levels to 27–30%, new burner designs have been introduced by several manufacturers in order to optimise combustion and increase the possible range of operating parameters. These are usually based on swirl burners which promote a high degree of recirculation of hot exhaust, sometimes in conjunction with injection of pure oxygen via oxygen lances; both of which act to accelerate ignition close to the burner. Improved understanding of the combustion behaviour at the level of the coal particle is also important for developing accurate CFD simulations tailored to oxyfuel combustion. Ongoing research in this area aims to ensure that the performance of pilot-scale combustion can be reliably translated to operation of a full-scale plant.

Recycle of flue gases before FGD or drying steps is an attractive option for raising plant efficiency, but may carry considerable added risk of both low- and high-temperature corrosion. Increased levels of water vapour and SO3 found in hot recycle schemes are known to raise the acid dew point and therefore require flue gas ductwork to be maintained above this temperature in order to avoid severe corrosion.

The influence of oxyfuel conditions on high-temperature corrosion of superheaters and waterwalls is harder to elucidate, and often contradictory results have been obtained from laboratory and pilot studies. However, corrosion in oxyfuel furnaces appears to adhere to familiar air firing mechanisms, with the recycle of SOx-rich flue gases presenting a similar risk to the use of high sulphur coals. Although increased water vapour levels increase corrosion rates of some alloys, metal carburisation due to CO2 appears to be effectively mitigated under oxidative conditions. It is likely that the corrosion risk will limit early oxyfuel plants to either less problematic fuels or more conservative flue gas recycle configurations with FGD.

As the most energy intensive plant process, the cryogenic air separation unit (ASU) is particularly in need of further development and adaptations specific to oxyfuel plant such as larger, more efficient, and more flexible units. In the last five years ASU manufacturers have reduced energy consumption of the unit by around 20%, primarily through use of more complex distillation process cycles such as three column or cold compression cycles, as well as implementing improved heat transfer and drying adsorbent technologies.

Whilst cryogenic ASU still has potential for further efficiency optimisation, the recovery of air compression heat for feedwater preheating is another useful means of minimising the overall efficiency penalty to the plant. Other developments include new technologies for the efficient storage of liquid oxygen, providing a cheap alternative to costly operation of the ASU during times of peak energy demand.

Although the ASU may prove to be a limiting factor in oxyfuel plant flexibility, as start-up of the unit from 'warm' can take days and air compressors have limited turndown, this could also be mitigted by the use of multiple compressor trains and stored oxygen. Ceramic membranes are a potentially higher efficiency alternative means of oxygen production, in which the absence of cryogenic cooling means that the energy of the hot, compressed air feed can be recovered after the oxygen is extracted. This technology has reached the pilot-scale but is not yet a commercial reality.

Although oxyfuel combustion can produce dried flue gases with over 90% CO2, the remaining fraction is largely made up of the light gases N2, O2, and Ar which would significantly raise the energy required to compress the product gas to pipeline pressures, as well as potentially exceeding the limits set by existing pipeline and EOR specifications. The partial condensation of the flue gases required to remove these species also imposes its own strict limits on flue gas contaminants in order to avoid damage to the sensitive compressors and cryogenic equipment.

Temperature swing adsorption is used for deep flue gas dehydration, while a variety of means for polishing of SOx, NOx and mercury to trace levels have been trialled at the lab-scale or in CPU operating at large oxyfuel pilots. These include conventional alkaline scrubs, pressure swing adsoprtion, distillation of NO2, and a novel sour compression process in which the chemistry of SOx and NOx at high pressure is exploited to promote their removal as condensates. CPU pilots have successfully demonstrated that achieving very high product CO2 purities is possible with a distillation step, although for future CO2-storage purposes a simpler flash separation may provide sufficient purity.

A disadvantage to conducting oxyfuel research at the pilot-scale is the necessary investment in a dedicated oxyfuel boiler, as opposed to the

power plant slip-stream tests which are possible for post-combustion capture pilots, and deployment of large oxyfuel pilots has therefore been less widespread. However, a number of pilots of over 20 MWth capacity have now been commissioned, with several including commercial ASU or pilot CPU in addition to the oxyfuel boiler.

Such pilots are able to provide invaluable experience in controlling the interaction of each of the plant processes in addition to standard boiler tests. As the largest oxyfuel pilot currently operating, commisioning of the 100 MWth Callide unit has demonstrated the importance of managing the array of chemical analysers in a full-chain oxyfuel process, as well as minimising the acidic corrosion and air ingress issues encountered by most pilots. Also in the early stages of planned test campaigns, the 30 MWth CFB unit at Ciuden is a unique facility for assessing the potential of oxyfuel CFBC, including the use of high levels of oxygen and the performance of in-situ desulphurisation.

Although several demonstration projects have reached advanced stages of design and planning, most have been hindered by the strong dependence on political and financial support inherent to all large-scale carbon abatement projects. However, with growing support from several national governments, current projects may meet with more succes. Of these, the proposed 168 MW FutureGen 2.0 plant in the USA is nearest to realisation, having reached an advanced stage of design and storage permitting. Other, less advanced projects in the UK and China may also receive sufficient government support to progress although, as with other capture projects, the deployment of a safe transport and storage infrastructure may present more of a barrier than the plant technology.

Amongst second-generation oxyfuel combustion concepts, pressurised combustion has attracted particular attention due to the high proportion of latent heat of water vapour which can be recovered, the reduction in air ingress, and the fact that some compression energy is saved in the CPU. In the most developed pressurised technology, currently operating at the 5 MWth scale, the high-temperature flameless combustion of coal slurry also has the advantage of significantly reduced emissions.

Other advanced oxyfuel processes have sought to reduce or eliminate flue gas recycle in order to reduce boiler size and improve combustion. Concepts at the research stage which combine both pressurised and low flue gas recycle include molten bed combustion and staged combustion, and development of such novel approaches is likely to continue. Without experience from demonstration projects, assessing the techno-economic performance of future commercial oxyfuel plant bears a high degree of uncertainty. Despite this, results of current analyses are in broad agreement that oxyfuel is at least economically competitive with other capture technologies to within the level of accuracy.

For retrofit purposes, oxyfuel may be a particularly suitable approach, as it avoids downgrading the steam turbine and can use a high proportion of existing plant equipment. Large-scale oxyfuel plant is variously estimated to impose an efficiency penalty of 6–10%pts on conventional coal plant, with the lower end of the range associated with a high degree of thermal integration of the three component processes and assuming ongoing progress in the optimisation of ASU and CPU efficiencies. Consequently, oxyfuel combustion could constitute a relatively efficient technology for a first generation coal CCS plant, and should be retained as a viable option alongside other capture processes by progression to a demonstration-scale.

The current state of oxyfuel technology

In oxyfuel combustion, coal is fired in a mixture of oxygen and recycled flue gases to produce a concentrated stream of CO2 which can be purified for sequestration through physical separation processes.

Despite the successful operation of a 30 MWth pilot plant since 2008, oxyfuel capture has yet to progress to the demonstration phase, however, the recent commissioning of a 100 MWth retrofit project and a 30 MWth oxyfuel circulating fluidised bed represent major steps for the technology. A number of new demonstration projects have also progressed to advanced stages of planning, of which the 168 MW FutureGen 2.0 plant could commence construction this year.

With operation at the pilot-scale well-established, ongoing oxyfuel research has focused on clarifying the complex effect of the altered gas composition on combustion, heat transfer, and corrosion mechanisms in the boiler.

As overall plant efficiency is limited by the substantial auxiliary loads required for oxygen production and purification of the CO2 product, optimisation of these processes is also key to future scale up. Commercial cryogenic air separation units can be thermally integrated with the plant's steam cycle for higher efficiencies, or potentially replaced by membrane-based processes currently in early stages of development.

New technologies trialled for CO2 purification have focused primarily on improving SOx and NOx removal and achieving almost complete CO2 capture.

www.iea-coal.org.uk

More information

The full report can be dowbnloaded from: **www.iea.org**

Projects and policy news

Boundary Dam project opens

www.saskpower.com

The world's first commercial-scale carbon capture and storage process on a coal-fired power plant was officially opened at Boundary Dam Power Station in Estevan, Saskatchewan.

Premier Brad Wall, Canada's Minister of Natural Resources Greg Rickford, Saskatchewan Economy Minister Bill Boyd, and SaskPower President and CEO Robert Watson officially opened the project. The launch was attended by more than 250 people from more than 20 countries representing governments, industries and media.

Shell Cansolv technology is being used to capture up to 90% of CO2 emissions from one train of the power plant. When fully optimized, SaskPower's new process will capture up to a million tonnes of carbon dioxide annually. The captured carbon dioxide will be used for enhanced oil recovery, with the remainder stored safely and permanently deep underground and continuously monitored.

"Over the past six years, Saskatchewan has become a global hub of innovation, especially in agriculture, mining, oil and gas, and now carbon capture and storage," Premier Wall said. "This project is another Saskatchewan first. The rest of the world is very interested to learn how they too can produce environmentally sustainable coal power."

"The opening of this new SaskPower plant reinforces the great innovation and development that can take place if you have strong investment and partnerships from the government and industry," said U.S. Senator Heidi Heitkamp (D-ND). "From my more than a decade working at Dakota Gasification in North Dakota, and from visiting the construction of the SaskPower facility just over a year ago, I understand just how important it is that we look to the future in how we harness our energy. Coal is a key resource in both Canada and the U.S., and through the development of clean coal technology, we can create North American independence and energy security, while also reducing emissions. We need to develop more clean coal plants to make that possible, and in the U.S., we can learn from the steps Canada has taken to find a realistic path forward for coal."

"This project is important because it is applicable to about 95 per cent of the world's coal plants," Economy Minister Bill Boyd said. "As nations develop emission regulations, they will come to us to see how we continue to provide affordable coal power to customers, but in an environmentally sustainable way."

Attendees at the event toured the facility and learned how they can access SaskPower's expertise and knowledge to develop their own CCS initiatives.

Brad Page, CEO of the Global CCS Institute

"This trailblazing project clearly demonstrates that carbon capture and storage (CCS) is possible on a large-scale in the power sector. Importantly, the lessons learned at Boundary Dam will help progress CCS projects internationally as a vital technology to meet our climate change challenge," said Mr Page.

The CAN$1.35 billion power project is the first in the world to use post-combustion CCS technology on a coal-fired power plant at large scale. SaskPower's CCS facility is estimated to capture 90% of emissions or 1 million tonnes of carbon dioxide each year. This is equivalent to taking more than 250,000 cars off the road.

"Capturing carbon from of our electricity generation system has the potential to provide the largest reductions in carbon emissions. Global forecasts predict fossil fuels will remain the world's primary energy source for decades to come. We simply can't have an effective response to tackling climate change without CCS," warned Mr Page.

Mr Page said CCS on power has a strong start with two more large scale CCS projects in the power sector under construction in the United States – Southern Company's Kemper County Energy Facility in Mississippi, and Petra Nova Capture Project in Texas.

Dr. Graeme Sweeney, Chairman of the Zero Emissions Platform

"We commend SaskPower and Canada for showing us all how it can be done. I believe that this event demonstrates that we are at the brink of a new era for CCS: we hope that Boundary Dam will help showcase to the rest of the world that full-scale commercial CCS is achievable and to kick start the development and deployment of this essential technology."

This project is a trailblazer for industry around the world and timely as Europe engages in concrete and important discussions around European energy and climate policies. Boundary Dam is a great example showing what can be achieved when industry and government come together for such an important cause. Europe will closely follow the progress on Boundary Dam, especially in light of promising advancements on European-based projects such as White Rose and Peterhead in the UK, ROAD in the Netherlands, and others. EU institutions and Member States will need to put in place transitional support measures for CCS.

"This achievement not only shows what can be done but provides an opportunity for international cooperation. Working together will help drive the deployment of CCS and drive learning for this essential technology."

TCM releases amine CO2 capture benchmarks

www.tcmda.com

Technology Centre Mongstad has completed the world's first open-source, large-scale CO2 capture tests of amine solvent MonoEthanolAmine (MEA) on flue gas from a gas-fired power plant.

The results prove that industrial-scale CO2 capture is technically and environmentally feasible to an extent never seen before, setting a benchmark for the CCS industry. The MEA campaign at TCM has given the CCS industry significant new insight into the operations of large amine plants treating gas-turbine flue gases.

Baseline solvent MEA is commonly used in post-combustion carbon capture studies to compare the performance of proprietarily-developed amines and other CO2 removal processes. The new test results are critical in setting a benchmark for the CCS industry. TCM is sharing some of the most important results openly with the global CCS community at the GHGT-12 conference in Austin, TX to increase knowledge and understanding of CO2 capture technology and to accelerate the full-scale deployment of CCS.

The results from the MEA test campaign at TCM prove energy demands for CO2 removal can be reduced from previously anticipated 4.1 GJ/ton CO2 removed to about 3.4 GJ/ton CO2 removed, while capturing 90% of the CO2 in the flue gas. This is a reduction in energy demand of about 20%, which will have a significant impact on reducing costs for full-scale CCS. The results also prove that the CO2 removal process can be undertaken in an environmentally safe manner, within the emission limits set by the Norwegian environmental authorities.

The use of amines to remove CO2 from industrial and natural gas streams is not new, with some amine systems for industrial and natural gas treatment dating back to 1930s. However, there has been a dearth of experience when using amines to remove CO2 from flue gases, as flue gases significantly differ from industrial and natural gas streams in terms of CO2 partial pressure, oxygen content, and various trace components such as SOx and NOx.

Until now, amine tests have been conducted under patents by independent vendors so there has been limited data available on CO2 capture operations from CCGT flue gas. Today, MEA solvent is no longer protected by patents, meaning TCM's results are open-source and available for use across the entire CCS industry. By thoroughly testing the MEA solvent in the amine plant and openly sharing that information, TCM stands to help technologists around the world maximise the performance of their technologies and advance the CCS industry on a major scale.

The MEA test campaign was designed to investigate the impacts of varying MEA concentrations, verify design capacity and flexibility of the plant and specific functionalities, and help understand scale-up, performance and emissions aspects.

Around 150 different plant run scenarios were investigated and the campaign also tested different online and offline techniques for emissions monitoring analysis. An important part of the MEA testing period was an independent test campaign conducted by the US-based Electric Power Research Institute (EPRI). The research results from this test campaign will be presented at GHGT-12 and stand as a notable contribution to research in the CCS industry.

Speaking from the GHGT 12 conference in Austin, Frank Ellingsen, Managing Director of TCM, said, "The conclusion of the first ever open source amine testing campaign on flue gas represents a huge milestone for the global CCS industry.

The MEA test campaign was conducted in collaboration with Aker Solutions as a part of its test period at TCM. The amine plant at TCM was designed and built by Aker Solutions and Kværner as a flexible test plant. It comprises an absorber, two stripping columns and a CO2 recycle line for increased CO2 inlet content.

Speaking from the GHGT 12 conference, Oscar Graff, Manager and CTO for CCS at Aker Solutions, said, "The significance of these results for the industry as a whole cannot be underestimated. The benchmark results of the MEA campaign have great value for Aker Solutions as a reference to our proprietary amines that have been tested at TCM over a period of about 12 months. The test results of our S21 and S26 solvents demonstrate significant reduction in degradation rates and improved energy efficiencies, indicating that we have developed robust solvents also suitable for more challenging types of flue gases."

Students discover their inner scientist at Mongstad

www.co2degrees.com

A group of students from Radøy Secondary School near Bergen got to test out life as a scientist as they took part in a CO2degees Education Workshop at TCM.

The students took an 'energetic look at energy' – with an interactive lesson on climate change and the need to limit CO2 emissions, followed by an afternoon of fun experiments helping them to learn more about carbon capture and storage technology.

The students were then challenged to communicate all they had been learning and demonstrate their favourite experiments on camera. The demonstrations will be used in Regina, Canada in just a few weeks' time, to teach students at the SaskPower CCS Education workshops more about low-carbon technologies.

Kirsty Anderson from the Global CCS institute led the education workshop and experiments. "Through our CO2degrees Education program we are trying to engage students around the world to learn more about CO2, energy and low-carbon technologies like CCS. The Radøy Secondary School students did such a great job demonstrating their favourite experiments – I think they discovered some serious skills in science communication!"

Lack of awareness and understanding are recognised as key barriers to the deployment of low-carbon energy technologies like carbon capture and storage (CCS), so the Global CCS Institute are making a conscious effort to improve access to the best education and outreach materials to help engage people around the world in discussions around low-carbon energy.

CarbonKids book can help children understand CCS

www.ukccsrc.ac.uk
www.co2crc.com.au

A book created by Western Australian primary school students will help children around the world better understand greenhouse gases and the process of carbon capture and storage.

The publication, "A Day in the Life of a Carbon Atom – Starring: Adom", is part of a

$200,000 Government sponsorship of CSIRO's CarbonKids program and will be distributed through the Global CCS education initiative.

The book was released concurrently at the 2014 National Carbon Capture and Storage Conference in Sydney, where Department of Mines and Petroleum Carbon Strategy Coordinator Dominique Van Gent presented copies to delegates.

Mines and Petroleum Minister Bill Marmion said he was particularly proud to see the talents of WA students on display at an international event. "To take a concept as complex as carbon capture and storage and create such an entertaining and, most importantly, easy to understand book is a big achievement," he said.

The book was written and illustrated by 21 Year Six and Year Seven students from St Michael's and negotiations are now underway for its distribution to schools participating in the Global Carbon Capture and Storage Institute's international education program.

The Minister launched CarbonKids in Western Australia in August last year, with $200,000 in Government sponsorship over two years to assist the CSIRO expand science education into regional areas.

UK study finds CCS struggling to be heard

www.ukccsrc.ac.uk

Awareness of carbon capture and storage technology remains "persistently low" amongst the British public whereas knowledge of fracking is high and growing, according to a recent survey conducted by Cambridge University on behalf of the UK CCS Research Centre.

These low levels of awareness about CCS could potentially undermine the UK's efforts to utilise the technology as a means of tackling carbon emissions from power plants and other facilities that burn fossil fuels, says one of the academics involved in the research.

The representative survey of over 2,000 people, conducted by the polling firm YouGov in late June, suggests that over 40% of the British public have never heard of CCS, with only 20% claiming to have read something about it in the past year. In stark contrast, awareness of fracking continues to grow dramatically, with those claiming to have never heard about it declining from 22% to just 5% within the past year, and views on the subject are becoming increasingly polarised.

Dr David Reiner of the Energy Policy Research Group at Judge Business School, University of Cambridge, who led the study, said: "As we seek to meet challenging longer-term carbon targets and build a low-carbon energy system, the public will be demanding value for money given the large sums involved.

The UK Government has ring-fenced £1 billion of public funds for capital construction of CCS demonstration projects and will be committing many millions more within the next year to support operating costs. Yet, despite CCS featuring regularly in the media, awareness of its role or progress remains very low amongst the public and, unsurprisingly, support for CCS remains tepid and has actually declined over the past year."

Dr Reiner will be speaking about the results of the survey as part of the event, The Carbon Conundrum, at the British Science Festival on Sunday 7 September.

As awareness of fracking grows by leaps and bounds, the survey found that opposition has increased relative to last year (from 26% to 34%), but so too has support increased (from 24% to 31%) as more people take sides in the shale gas debate. By contrast, support for using CCS with coal-fired electricity generation dropped from 41% in 2013 to 28% this year. Less than 2% of the British public could name any aspect of the CCS demo projects.

This is the first public survey in the UK that compares attitudes on fracking and CCS. It is also the first to assess evolving attitudes to CCS in general, and to the two UK demonstration projects in particular. Results from the survey are currently being analysed and will be published as an EPRG working paper within the next 2 months.

New Australian labs for CCS research

www.co2crc.com.au

An $18 million CO2CRC–University of Melbourne contract for new laboratories, plant and equipment will be used in a range of CCS activities over the next five years.

The new facilities, including laboratories for CCS geochemistry and carbon capture chemical engineering, basin attribute modelling, 3D visualisation, seismic networks and dynamic simulation, will be built, maintained and operated by The University of Melbourne. The University's Peter Cook Centre for CCS Research will offer two new professorial positions to work in the labs.

The infrastructure contract announced today is part of the $86 million CCSNET project established between the Cooperative Research Centre on Greenhouse Gas Technologies (CO2CRC) and the Commonwealth Department of Education in August 2013 under the Education Investment Fund (EIF) for large-scale CCS Flagship projects. The EIF is providing $51.6 million.

The University of Melbourne's Deputy Vice-Chancellor (Research), Professor James McCluskey, said the new laboratories would support national and international work to enhance CCS as a technology for tackling climate change. "With support from the CCSNET project, the University of Melbourne is able to make a significant contribution to advancing CCS technology," Professor McCluskey said.

"The University aims to become a world leader in developing innovative and more cost efficient CCS methods and, more broadly, establish Australia as a world leader in the technology. This investment will allow us to make great strides toward this goal."

CO2CRC CEO Dr Richard Aldous said he was delighted to see CO2CRC's plan for investment in national CCS research infrastructure starting to come to fruition. "The Commonwealth funding is important for building new capability in CCS through a network of field facilities, onshore and offshore monitoring systems and world class laboratories," Dr Aldous said.

"CCS is the only technology that can achieve substantial cuts in emissions from industrial-scale use of fossil fuels. So as the need for action on climate change becomes more pressing, Australia must be ready to deploy CCS technology."

CCSNET primarily supports Victoria's CarbonNet Project, which is funded under the CCS Flagships program, although the facilities are available for other Australian CCS projects and, potentially, international collaborators.

The CCS Flagships Program enables demonstration of large-scale integrated CCS projects in Australia, with the aim of widespread deployment of the technology from 2020.

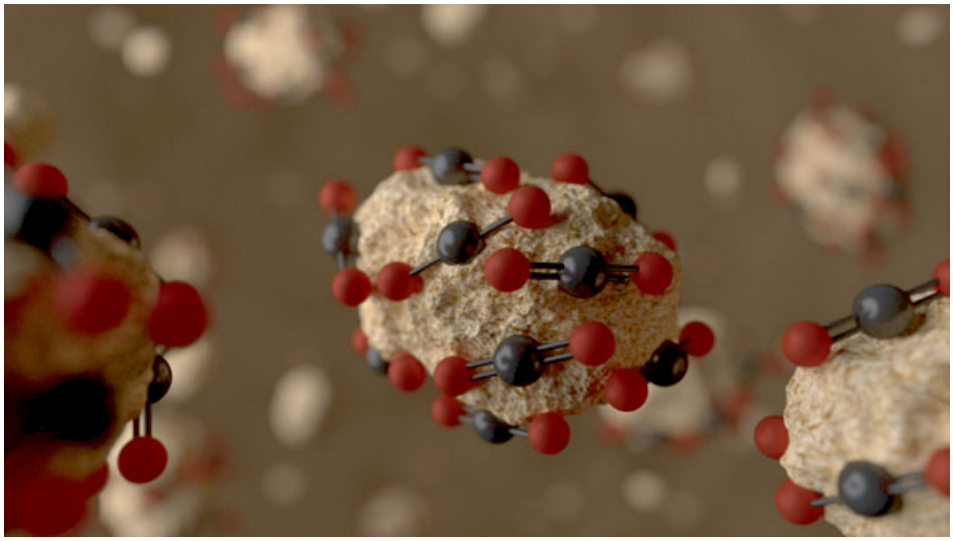
Capture and utilisation news

Low cost carbon capture slurry developed

www.epfl.ch

A new approach to carbon capture uses a mixture of solid and liquid in solution called a 'slurry'.

Collaborating scientists from Ecole Polytechnique Fédérale de Lausanne (EPFL), UC Berkley and Beijing have combined carbon-capturing solids and liquids to develop a "slurry" that offers the best of both worlds: as a liquid it is relatively simple to implement on a large scale, while it maintains the lower costs and energy efficiency of a solid carbon-capturing material. The breakthrough method is published in Nature Communications.



Scientists from EPFL, UC Berkeley and Beijing have developed a slurry-based process that can make carbon capture more efficient. The slurry consists of a porous powder suspended in glycol. © 2014 EPFL Jamani Caillet

The most common approach to carbon capture uses liquid amine solutions, which can absorb CO2 from the atmosphere. On a large scale, the system uses two columns, one for capturing CO2 and the other for releasing it from the liquid, in a process referred to as "regeneration". For amine solutions, regeneration is the most energy-consuming part because the CO2 is so strongly bound to the amine molecules that it is necessary to actually boil them in order to separate them.

An alternative to liquids is to use solid materials known as "metal-organic frameworks" (MOFs). These are fine powders whose particles are made up of metal atoms that are connected into a 3D structure with organic linkers. Their surface is covered with nano-size pores that collect CO2 molecules. But despite its lower cost, as this method involves transporting solids it is very demanding in terms of engineering.

Berend Smit, Director of the Energy Center at EPFL, explains: "Imagine trying to walk with a plateful of baby powder. It's going to go everywhere, and it's very difficult to control."

Working with scientists from Beijing and UC Berkeley, Smit is a lead author on a breakthrough carbon-capture innovation that uses a mixture of solid and liquid in solution called a "slurry". The solid part of the slurry is a MOF called ZIF-8, which is suspended in a 2-methylimidazole glycol liquid mixture.

"Why a slurry?" says Smit. "Because in the materials that are currently used for adsorption the pores are too large and the surrounding liquid would fill them, and not let them capture CO2 molecules. So here we looked at a material – ZIF-8 – whose pores are too small for the glycol's molecules to fit, but big enough for capturing the CO2 molecules from flue gas."

ZIF-8 is a good material for carbon-capturing slurries, because it displays excellent solution, chemical and thermal stability, which is important for repeated regeneration cycles. ZIF-8 crystals have narrow pores (3.4 Å in diameter) that are smaller than the diameter of glycol molecules (4.5 Å), preventing them from entering.

Even though other liquids were tested in the design of the slurry, including ethanol, hexane, methylbenzene and tetrachloromethane, their molecules are small enough to enter the ZIF-8 pores and reduce its carbon capturing efficiency. In this respect, glycerol has so far been shown to be an ideal liquid.

The concept of the slurry comes from an idea from one of Smit's former PhD students who is now a professor in Beijing, and it could be the key to large-scale implementation of carbon capture. "Pumping slurry is much easier than transporting a pile of baby powder," says Smit. "And we can use the same technologies for heat integration as the liquid process."

Because it combines the low cost and efficiency of nano-porous materials with the ease of a liquid-based separation process, the slurry successfully addresses these two main obstacles to the implementation of carbon capture in the real world. In addition, it shows exceptionally good separation from CO2, meaning that it doesn't require excessive amounts of energy (e.g. boiling) in order to regenerate, which increases its overall energy efficiency.

The slurry represents a new template for developing similar combinations in the future. Following their successful proof-of-concept work, the research teams are now planning to test the ZIF-8/glycol slurry in the field.

The research is published by Liu H, Liu B, Lin L-C, Chen G, Wu Y, Wang J, Gao X, Lv Y, Pan Y, Zhang X, Zhang X, Yang L, Sun C, Smit B, Wang W. A hybrid absorption–adsorption method to efficiently capture carbon. Nature Communications DOI: 10.1038/ncomms6147.

CO2 Solutions announces testing program with EERC

www.undeerc.org

CO2 Solutions Inc. has signed an agreement with the University of North Dakota Energy & Environmental Research Center (EERC).

With the Agreement, CO2 Solutions joins EERC's program Advancing CO2 Capture

Technology: Partnership for CO2 Capture (PCO2C) Phase III as a sponsor.

Under the program, CO2 Solutions will test its technology at EERC's existing testing facility using natural gas and coal flue gas in December, 2014. The program's goal is to evaluate several CO2 capture technologies that are among the most advanced systems under development for application to power and steam generation plants.

The tests will have approximately twice the capacity of the Corporation`s largest testing to date. Data from the EERC program is expected to provide valuable input for the pilot initiative to run with Husky Energy in 2015. Additionally, it will provide additional performance benchmarking of CO2 Solutions' enzyme-accelerated process against other solvent-based processes.

"We are excited to welcome CO2 Solutions to the PCO2C program," said John Kay, EERC Senior Research Manager. "We believe its enzymatic technology holds considerable promise as a new, lower-cost approach for carbon capture, utilisation and sequestration".

The testing program is supported financially in part by the U.S. Department of Energy (DOE). Certain results of CO2 Solutions' testing will be made available to the program consortia, which includes the DOE, other leading CO2 capture technology providers, major energy companies, and electric utilities.

FuelCell Energy project moves to phase three

www.fuelcellenergy.com

FuelCell Energy has received $1.2 million to continue into phase three of the project.

The project focuses on using Direct FuelCell® (DFC®) technology to efficiently and cost effectively separate carbon dioxide from the emissions of coal-fired power plants. After achieving the project design and financial goals established for phases one and two, FuelCell Energy will continue into phase three of the project including the validation of the CO2 capture process using a DFC fuel cell stack.

The project is supported by funding from the U.S. Department of Energy and is being implemented by the National Energy Technology Laboratory

A FuelCell Energy installation - the company's Direct FuelCell technology can be used to capture power plant emissions while also producing additional power

"This project is making measurable progress for providing an efficient and cost effective carbon concentration and capture solution for coal-fired power plants, which has compelling market applicability," said Chip Bottone, Chief Executive Officer at FuelCell Energy. "This next phase of the project advances the solution to demonstrate a commercial fuel cell stack, which is a significant step towards commercialization."

Analysis already undertaken illustrates that the DFC CO2 capture systems have advantages over existing commercial technologies, due to their ability to capture CO2 from fossil based power plants while also producing additional power. The results have indicated that the DFC carbon capture plants have the potential of meeting the DOE's carbon capture cost goal of $40/ton for commercial applications.

The project began in late 2011 with funding for the project being awarded in stages as progress milestones are reached. The final $1.2 million DOE award of the total $3 million project is now authorized to further advance the carbon capture system. This funding authorization follows favorable results achieved from the technology and economic analysis conducted in the prior stages of research and development.

This third stage includes validation of the DFC technology capabilities by using a fuel cell stack to separate 90% of CO2 from a simulated coal gas plant exhaust. This test will be the final stage of the validation for the technology before field trials using a DFC power plant.

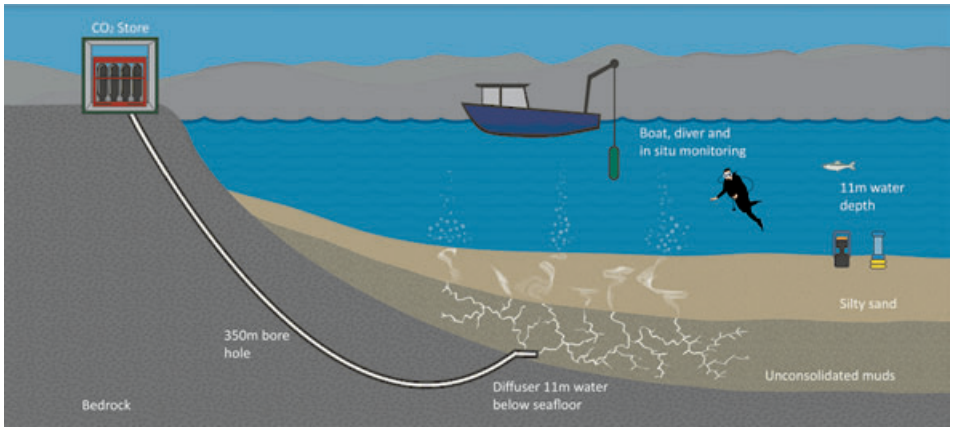
FuelCell Energy's DFC technology separates and concentrates CO2 as a side reaction during the power generation process. In this application of the technology, the exhaust of a coal fired plant is directed to the air intake of a DFC power plant, which separates and concentrates the CO2 in the exhaust for commercial use or sequestration.

Another side reaction that occurs when the fuel cell is used in this application is the destruction of 60 to 70 percent of smog-producing nitrogen oxide (NOx) emissions in coal plant streams as the exhaust passes through the fuel cell. This reduces the cost of NOx removal equipment for coal-fired power plant operators while benefiting the environment.

Since DFC power plants produce power efficiently and with virtually zero emissions, the net result is a very attractive solution to prevent the release of green-house gases by coal-fired power plants while simultaneously increasing the net efficiency and power output of the plant. Additional benefits include reduction of the operating cost related to removal of NOx and reduction in water usage as existing carbon capture technologies are water intensive.

Sub-seabed CO2 leak experiment shows minimal environmental impact and rapid recovery

The world-first experiment on a controlled sub-seabed CO2 leak showed minimal impact on wildlife limited to a small area.



The study looked at the impact of a small CO2 leak on marine wildlife and ways to detect and monitor the gas that is released

An international team of scientists have published results of the first ever sub-sea carbon dioxide impact, detection and monitoring experiment relevant to Carbon dioxide Capture and Storage (CCS) in sub-seabed storage reservoirs in Nature Climate Change.

The study was designed to understand how marine life on the seabed and in the water above might react to a real-life leakage, as well as determine methods for detection and monitoring of a small-scale carbon dioxide (CO2) leak event. The research found that, for a leak of this scale, the environmental damage was limited; restricted to a small area and with a quick recovery of both the chemistry and biology.

The Quantifying and Monitoring Potential Ecosystem Impacts of Geological Carbon Storage (QICS) project was led by Plymouth Marine Laboratory's (PML) Jerry Blackford and funded by the Research Councils UK, the Natural Environment Research Council, the Scottish and Japanese Governments. A number of UK and Japanese institutes collaborated with the experimental controlled release of CO2 undertaken in Ardmucknish Bay, (near Oban) Scotland in 2012; the experiment was co-ordinated by the Scottish Association for Marine Science (SAMS).

4.2 tonnes of CO2 (less than the annual CO2 emission of a gas-heated UK home*) was injected over 37 days from a land-based lab via a borehole drilled through rock to the release site, 350 meters from the shore and 11 meters below the seabed (see illustration below). Scientists initially monitored how the CO2 moved through the sediment and the 12 meters of water above. Over the following 12 months the impact on the chemistry and biology of the surrounding area was assessed using a combination of techniques, including chemical sensors, listening for bubbles and diver-mediated sampling.

A combination of chemical sensors and bubble acoustic techniques are shown to provide the optimal monitoring technology to detect leakage or give assurance of no leakage.

The impact of this simulated leak shows that the impact of escaped CO2 on a similar scale would be limited. CO2-induced chemical changes occurred towards the end of the CO2 release but impacts including changes to environmental chemistry returned to background levels within 17 days of turning off the CO2 release.

No biological effect was observed during the early stages of the release. At the end of the release period and early in the recovery period, there was a change in seabed-dwelling communities as well as the gene expression of microbes. These impacts were not catastrophic or long lasting and full recovery was seen in weeks.

Project leader Jerry Blackford, at PML, said: "These findings are contributing to the growing knowledge base necessary for optimal deployment of CCS as a climate change mitigation measure; in particular for the regulatory requirement for monitoring. The results show that small-scale leakage will not be catastrophic, although we do caution that impacts are likely to increase if a larger amount of CO2 is released. Water movement in the area is also important; impacts are estimated to be less and recovery quicker in environments with stronger water mixing so that the CO2 is dispersed more rapidly.

This study did not address the integrity of storage in reservoirs situated 1km or more below the sea floor, but addressed the "what if" scenario of leakage at the seabed. Leakage of CO2 from storage reservoirs is thought to be unlikely.

Recommendations for CCS operators developing risk strategies are:

• CCS site selection should be below dynamic bodies of water to promote dispersal of CO2 in the unlikely event of leakage.

• A comprehensive baseline study, encompassing sediment structure and content, sea water chemistry, biological community structure and ambient noise, is required to maximise monitoring efficiency.

• A combination of chemical pH and bubble-listening sensors will maximise early leakage detection or alternately provide assurance that leakage is not occurring.

More information

www.pml.ac.uk

Transport and storage news

DNV GL releases experimental data on CO2 pipeline design

www.dnvgl.com

DNV GL has made new data available which will help make CO2 pipelines safer and more efficient.

New data relating to the depressurisation of CO2 pipelines is being made freely available through the DNV GL-led CO2PIPETRANS joint industry project. This will help fill knowledge gaps associated with the safe and reliable pipeline transport of CO2 and result in cost efficiencies through a significantly improved design basis for CO2 pipelines, said the company.

Computer simulations of gas dispersion are used to assess the consequences of an accidental release from a pipeline. "Previously, CO2 pipelines have been designed using unvalidated computer simulations of CO2 dispersion due to the lack of experimental data. This uncertainty contributes to an unnecessary gold-plating of the pipelines," says Project Manager Jock Brown, DNV GL – Oil & Gas, speaking at the GHGT-12 conference in Austin, Texas.

"This new data is one step in the right direction. It builds on the success of previous experimental data released by DNV GL and can be used by the CCS industry and designers to validate computer simulations used in CO2pipeline design, thus optimising the design process," he continues.

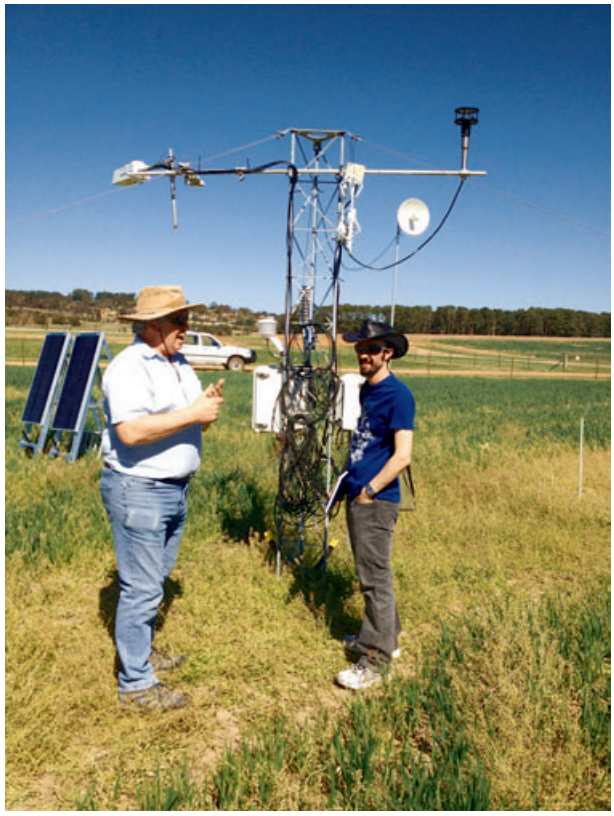
The datasets contain the results of depressurisation tests on a CO2 pipeline collected at the DNV GL Spadeadam test site in the UK as part of the second phase of the CO2PIPETRANS JIP started in 2011. The data and other material supporting the use of the data can be downloaded free of charge.

In addition to making datasets for model validation publicly available, the JIP also involves work to improve the understanding of CO2 pipeline propagating cracks and corrosion rates with various CO2 stream impurities.

"This project is one of around 30 joint industry projects we run annually, bringing together industry players in a neutral environment to close technical knowledge gaps and fast track innovation. We have a strong track record of industry collaboration on CCUS, for example through the CO2RISKMAN. The CO2PIPETRANS project will drive the technology price curve down and help speed up the roll out of CCUS technology," says Elisabeth Tørstad, CEO of DNV GL Oil & Gas.

The CO2PIPETRANS JIP consists of 15 partner organisations: Arcelor Mittal, BP, DNV GL, Endesa, ENI, E.ON Ruhrgas, Gassco, Gassnova, Health and Safety Executive (HSE) UK, Maersk Oil, Petrobras, Petroleum Safety Authority (PSA) Norway, Shell, V&M Deutschland, and Vattenfall.

The DNV GL Recommended Practice 'DNV-RP-J202 Design and Operation of CO2 Pipelines' will be updated to reflect the new knowledge and help ensure that the highest safety standards are met when transporting CO2. The data is freely available on DNV GL's website.



CO2CRC and Geoscience Australia are testing CO2 monitoring techniques at the Ginninderra facility

Geoscience Australia testing CO2 monitoring techniques

www.ngl.org.au

A controlled release facility, hosted at the CSIRO's Ginninderra Experimental Station in north Canberra, is designed to simulate surface emissions of greenhouse gases.

The facility is jointly run by the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) and partner agency Geoscience Australia and is one of only a few similar facilities around the world. The work at the Ginninderra facility complements the monitoring work being undertaken by the CO2CRC and Geoscience Australia at the Otway Project in Victoria.

The measurement of known releases of greenhouse gases in the field using a controlled release facility is the most effective approach for assessing the effectiveness of monitoring techniques, said Geoscience Australia. Project Leader Dr Andrew Feitz said one of the key challenges is to develop technology for detection of small-scale leak features over a wide area.

"This project has seen development of world leading research into the use of mobile sensor and remote sensing technology at the site," Dr Feitz explained.

The project facility was designed and developed under a joint venture between the CO2CRC and Geoscience Australia to evaluate the effectiveness of different near surface monitoring techniques for detecting and quantifying leaks against a known CO2 source.

The research conducted at the facility has been a highly interdisciplinary collaborative project with a range of national and international partner organisations. The research team has come from a broad range of scientific disciplines, including atmospheric science, geochemistry, plant biology and engineering.

The mix of different disciplines has provided insight into the behaviour of a controlled released CO2 plume in the near surface, the effectiveness of different monitoring approaches, and identified the key challenges for monitoring at geological sites now and into the future.

Some of the key results from the monitoring experiments conducted at the Ginninderra Experimental Station will be presented at the upcoming Greenhouse Gas Technologies Conference in Austin, Texas in early October.

$5 million ensures continuation of Otway Project

www.co2crc.com.au

The Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) has welcomed the announcement by Victoria's Ministry for Energy and Resources of an additional $5 million for research in CO2 storage at the Otway site.

CO2CRC CEO Dr Richard Aldous today said the announcement, which followed a highly instructive examination of the international progress of carbon capture and storage (CCS) at Australia's biennial National CCS Conference last week, showed the Victorian Government recognises the important role the technology has to play in tackling climate change.

Dr Aldous said the CO2CRC Otway Project had clearly shown that CO2 storage was a safe credible long-term option for mitigating emissions that would otherwise be released into the atmosphere and contribute to further damaging climate change.

In fact, CCS is currently the only available method of making significant cuts to emissions from fossil fuel-powered energy generation and large industrial processes, such as refining oil or producing iron, steel, cement and ammonia.

"Otway offers one of the most comprehensive CO2 monitoring programs of its type in the world, providing technical information on geosequestration processes, technologies and monitoring, as well as verification schemes," he said.

"Appropriate government policy, including funding initiatives and other enabling mechanisms, is fundamental to the successful development, demonstration and deployment of new technologies. "The Victorian Government's additional funding means that new experiments will proceed at Otway."

UW wins DOE grant for further study of Rock Springs Uplift

www.uwyo.edu

A new grant from the U.S. Department of Energy will allow an interdisciplinary team of University of Wyoming scientists to further study how injecting CO2 into the Rock Springs Uplift would affect underground conditions.

The $1.1 million grant, which takes effect Oct. 1, will help fund a three-year research project to predict changes in the subsurface during and after injection of CO2. Research has shown that two deep saline aquifers in Sweetwater County's Rock Springs Uplift could store 26 billion tons of CO2 over 50 years as part of a future carbon capture and storage operation.

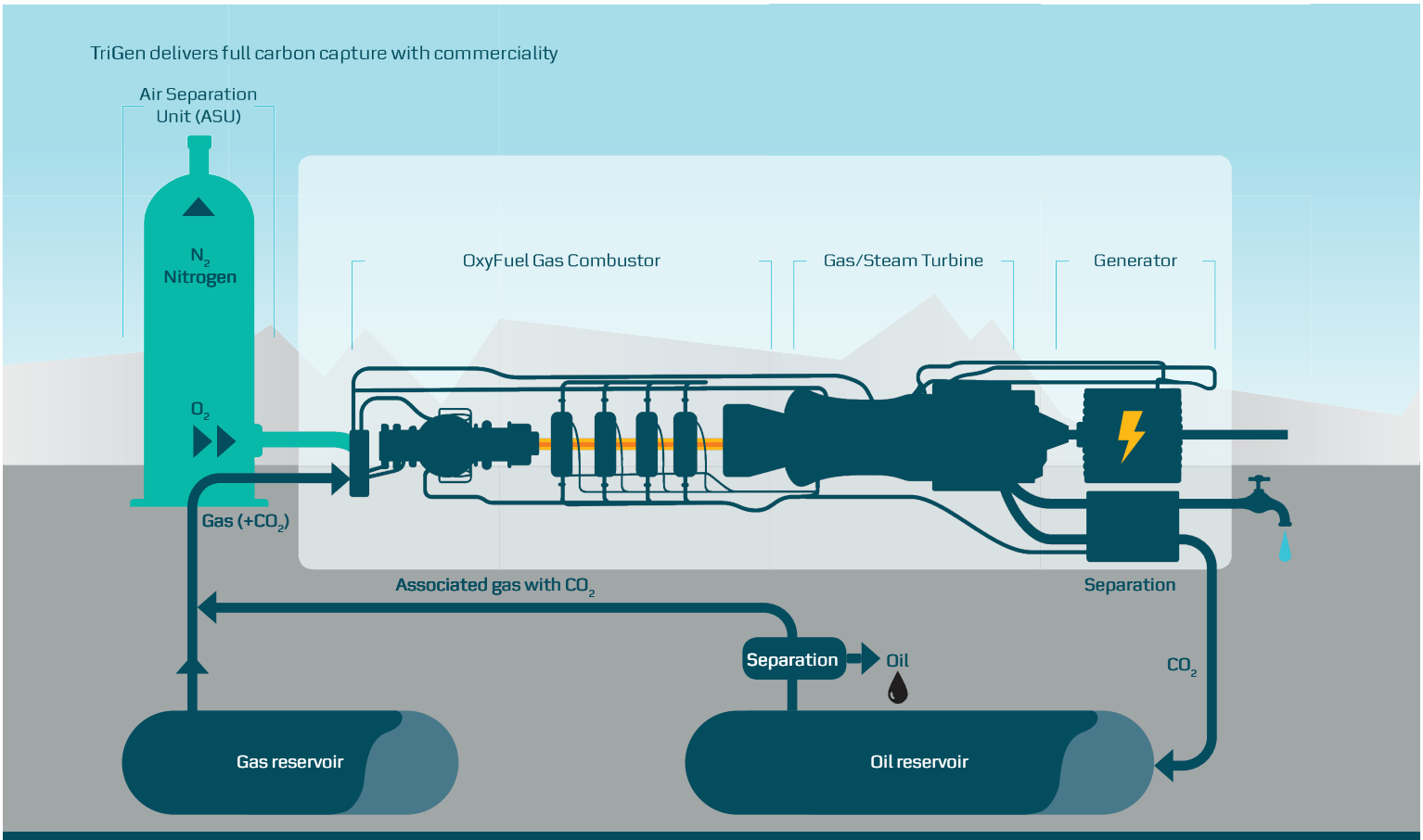
"The goal of this research is to improve our understanding of the geomechanical effect of CO2 injection on two types of reservoir rocks, sandstone and limestone/dolomite," says John Kaszuba, associate professor in UW's Department of Geology and Geophysics and the School of Energy Resources (SER). "The ability to predict geomechanical behavior in response to CO2 injection, if successful, could increase the accuracy of subsurface models that predict the integrity of the storage reservoir."

UW researchers in 2009 began a study of the Rock Springs Uplift, with funding from the Department of Energy and the state of Wyoming, to determine its potential for storing CO2.

UW's Carbon Management Institute, one of SER's centers of excellence, led the effort, which included the drilling of a 14,000-foot test well. The project resulted in a thorough characterization of the Rock Springs Uplift as a potential commercial-level geological CO2 storage site.

"The new research will build upon the strong foundation of studies that have been completed on the Rock Springs Uplift, such as field work and subsurface characterization of lithology, structure, mechanical stratigraphy, fracture systems and in situ stress," Kaszuba says.

The research also could provide insights for the oil and gas industry, which uses CO2 injection to enhance the recovery of oil and gas.



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