Carbon Capture Journal

CCS in Canada

CMC Research Institutes opens facilities to XPrize teams

CO2 Solutions' enzyme catalyst

Technical potential for CCS in Saskatchewan

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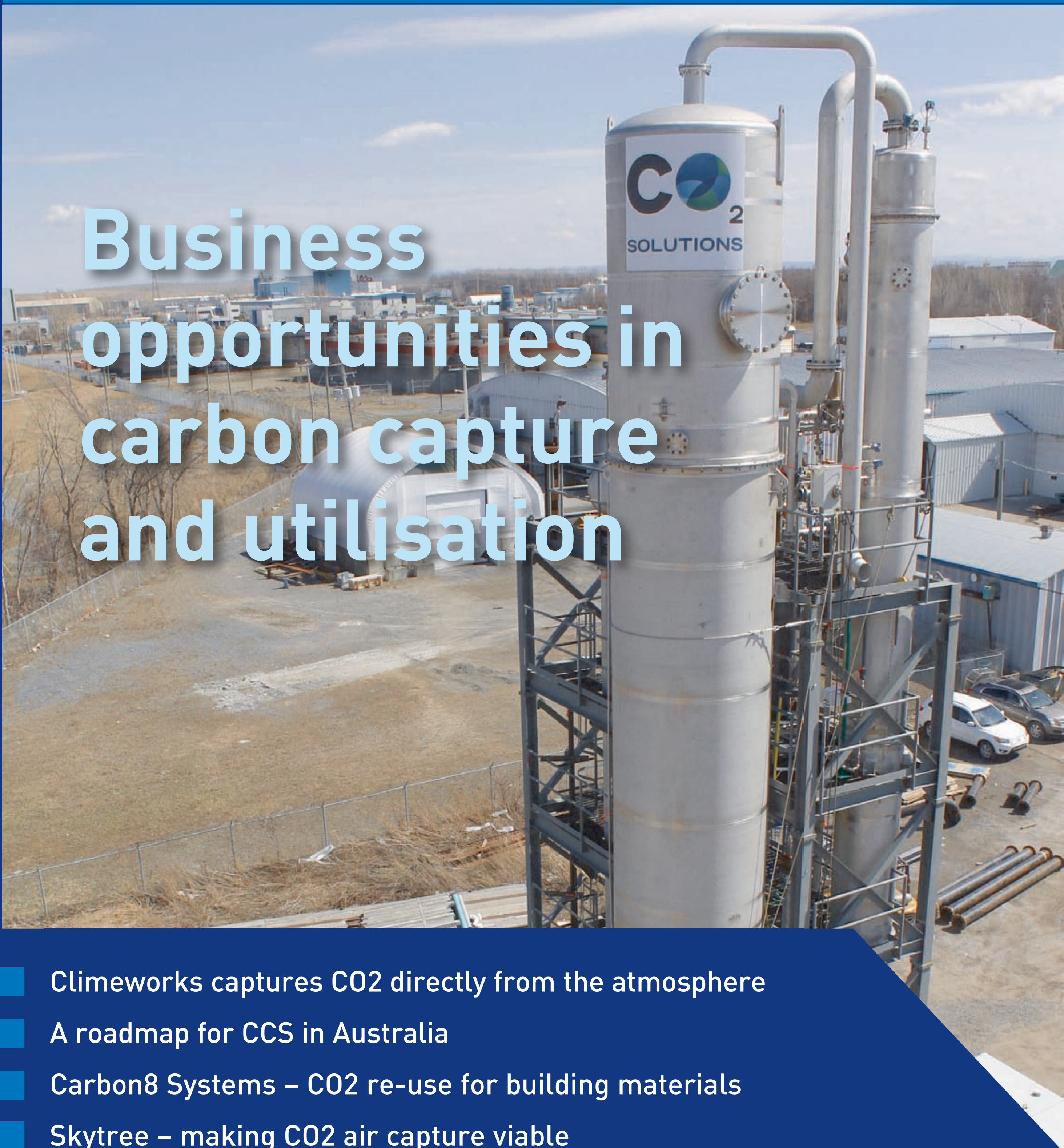

Business opportunities in carbon capture and utilisation

- Climeworks captures CO2 directly from the atmosphere
- A roadmap for CCS in Australia
- Carbon8 Systems – CO2 re-use for building materials
- Skytree – making CO2 air capture viable

ETS Reform: Solution or façade?

On 15th of February, the European Parliament accepted a proposal on the reform of the EU Emissions Trading System (ETS). The proposal is meant to ensure a more cost-effective system of emission reductions and an overall increase of low-carbon investments across the EU. Despite some slight improvements in the provisions of the Directive, there are also some setbacks. Alongside Carbon Capture and Storage (CCS), the revised proposal gives prominence to carbon capture and utilisation (CCU), which does not prevent emissions from being created but merely delays their discharge.

By Bellona Europa

The voted upon revision of the EU ETS consists of several main elements:

• Regarding the ambition of the Directive, the Parliament suggested consistent monitoring and revision of the linear reduction of emission allowances, which should amount to a reduction of 2.2% per year starting 2021.

• Apart from continual control of the level of commitment, additional measures should address carbon leakage, particularly in the most sensitive industry sectors.

• The proposal suggests the creation of a more dynamic allocation system. With this revision, changes in allocation will be possible when there is a corresponding 10% increase or decrease in production of an installation.

• There will be a simplification of the system, particularly for the small emitters.

• Most importantly, the revisions include provisions for the Innovation and Modernisation Funds.

An ambitious EU ETS is, however, only one piece of the puzzle and should not be the sole beneficiary of EU policy support. A more diversified approach is necessary if we are to successfully tackle emission reductions in EU member states.

According to the IPCC, the Paris agreement targets will not be feasible unless CO_2 concentrations are reduced by the deployment of CCS technologies. The latter could be successfully supported through the favourable design and implementation of the Innovation fund, which could offer vital opportunities for the successful dissemination of CCS facilities and can ensure the further development of infrastructure for CO_2 transport and storage.

The newly accepted boost of the Innovation fund is a valuable revision, yet the allocation processes must favour key technologies such as CCS in order for the policy to remain effective. Strategically positioned policy initiatives and infrastructure are, along with additional resources, important for the large-scale deployment of CCS in the EU.

By providing more opportunities for CCS, the establishment of low-carbon zones could stimulate job creation and further investments. The suggested encouragement in the form of EU ETS allowances will hopefully also serve as a catalyst for CCS deployment.

The creation of an import inclusion scheme, as suggested in one of the amendments of the Directive, would also be an efficient way of addressing the ever-growing emissions in the EU. This scheme could help industries in developing low-carbon solutions that would be more suited for the future European market.

Despite some slight improvements in the provisions of the Directive, there are also some setbacks. Alongside CCS, the revised proposal by the Parliament gives prominence to carbon capture and utilisation (CCU), which is a method that should not be put into the category of renewable solutions to the climate change issue.

Since CCU is a method that consists of converting the captured CO_2 into fuels, it does not prevent emissions from being created but rather delays their discharge. It is a process that further aggravates the problem, rather than solving it and should hence not be presented as a satisfying climate-technology.

Resources should not be wasted on technologies that are ultimately inadequate methods of addressing climate change, but should rather be put to use for deploying technologies that will make a difference in reaching the 2 degree goal.

BellonaBrief: CCU in the EU ETS: risk of CO2 laundering preventing a permanent CO2 solution

The usage/utilisation of captured CO_2 (CCU) is incorrectly mentioned to be an equivalent alternative to CCS. While there are methods of permanently storing CO_2 by using CCU technologies, such as mineralisation, the usage of captured CO_2 in chemicals and fuels does not contribute to significantly lowering the level of CO_2 in the atmosphere.

Synthetic fossil fuels produced by adding captured CO_2 to clean, renewable hydrogen (H_2) is wrongly branded as "renewable natural gas". Fossilising hydrogen to produce synthetic methane merely delays the CO_2 from being emitted.

The distinction between permanent (e.g. CCS and mineralisation) and temporary solutions (e.g. synthetic methane and chemicals) must be made when considering to invest in solutions that are meant to resolve the major challenge of limiting and reducing the level of CO_2 in the atmosphere.

Although a CCU infrastructure can be a stepping stone for the deployment of CCS, there is a real danger that governments will boost the profitability of CCU for industries. This will likely form an obstacle that prevents permanent CO_2 solutions from being developed.

More information

Download 'CCU in the EU ETS: risk of CO2 laundering preventing a permanent CO2 solution'.

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Front cover: CO2 Solutions' 10 tonne per day pilot project has validated CO2 capture for less than $40/tonne (Image ©CO2 Solutions)

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CMC Research Institutes opens facilities to XPrize teams

A new technology commercialization centre on Canada's West Coast has opened its doors to international innovators participating in a US$20-million global competition to convert carbon dioxide emissions into valuable products.

By Mark Lowey

The Carbon Capture and Conversion Institute's (CCCI) new centre, located in metropolitan Vancouver in the province of British Columbia, is offering its facilities and network of experts to 27 semi-finalist teams competing in the NRG COSIA Carbon XPRIZE. The worldwide competition challenges teams to develop breakthrough technologies that convert the most carbon dioxide from industrial emissions into products with the highest net value – thereby keeping the greenhouse gas out of the atmosphere.

NRG COSIA Carbon XPRIZE team with partners, sponsors and competitors

CCCI is an institute of CMC Research Institutes, a federally incorporated not-for-profit company dedicated to accelerating innovation to eliminate industrial greenhouse gas emissions. Under a partnership agreement between CMC Research Institutes, XPRIZE and competition sponsors NRG and Canada's Oil Sands Innovation Alliance, all 27 teams from six different countries – including nine teams from Canada – have the option of utilizing CCCI's new centre during the solutions-development phase. Advancing carbon capture and conversion technologies from the laboratory bench to pilot plant scale is a requirement for teams to advance to the competition finals.

Headquarters of the new Carbon Capture and Conversion Institute in Richmond, B.C. (artist's rendering)

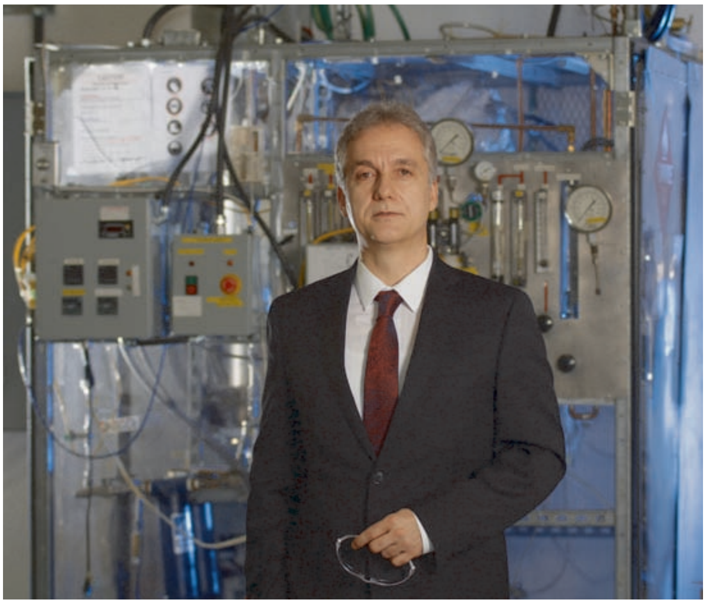
Scheduled to open by March this year, CCCI's custom-built Technology, Commercialization and Innovation Centre is operated by a multidisciplinary team of professionals, including scientists and engineers, and is focused on scale up and commercialization.

"We're very excited about this partnership, especially the opportunity we have to help and support the semi-finalists in developing and testing their technology," says Goran Vlajnic, CCCI's executive director.

"I'm happy that NRG COSIA Carbon XPRIZE recognizes the specific value and expertise that CMC Research Institutes and the CCCI, together with their national and international networks of researchers and engineers, can bring to the table to help these semi-finalists." The partnership will strengthen Canada's position as a global leader in the development of low-carbon technologies and contribute to the thriving clean tech sector in British Columbia's Lower Mainland, Vlajnic adds.

With the new centre, CCCI and its set of skills and capabilities will help ensure a fair assessment of the competitors, especially with so many novel technologies at a fairly early stage. In a letter of support for the institute, Paul Bunje, XPRIZE's principal and senior scientist for the Energy & Environment Group, said the institute's "globally unique facilities . . . are attracting substantial attention, engagement and investment from government and academic research labs as well as private industry in the U.S., Norway, Germany, the UK, the EU and elsewhere."

CCCI and its new technology commercialization centre offer "exactly the type of implementation and scaling expertise that is needed by many of the semi-finalist Carbon XPRIZE competitors," Bunje wrote.



"Together with our partners, we can provide not only extensive knowledge and expertise in process and equipment design and engineering, but also in scale-up and fabrication." - Goran Vlajnic, executive director, Carbon Capture and Conversion Institute

New centre offers semi-finalists several advantages

Vlajnic says the Carbon Capture and Conversion Institute's $4.5-million (for construction and furnishings) Technology, Commercialization and Innovation Centre, built with CCCI's partner BC Research, offers several advantages to help semi-finalists accelerate the design, engineering and scale-up of their technologies. To advance to the final round, the teams must be able to demonstrate a carbon dioxide conversion system at 200 kilograms CO2 per day throughput.

The centre is designed to facilitate the development and testing of various carbon capture and conversion technologies, from the scale of tens of kilograms CO2 per day up to one to two tonnes CO2 per day. Technologies are scaled up from concept to pilot or demonstration scale by BC Research-CCCI's experienced team of scientists, engineers and designers.

"This is what we believe sets us apart from other similar organizations," says Vlajnic, who sees the institute as a 'one-stop shop' for the competing teams. "Together with our partners, we can provide not only extensive knowledge and expertise in process and equipment design and engineering, but also in scale-up and fabrication."

Through CMC-CCCI's extensive network, we can also help some of the semi-finalists develop or further refine their business models."

The centre will provide an actual flue gas stream from a natural gas-fired boiler as well as a simulated flue gas stream that can be mixed to replicate different industrial processes, including flue gas from a power plant burning coal.

"Exactly the type of implementation and scaling expertise that is needed by many of the semi-finalist Carbon XPRIZE competitors." - Paul Bunje, principal and senior scientist for the Energy & Environment group, NRG COSIA Carbon XPRIZE

This is crucial to NRG COSIA Carbon XPRIZE competitors, because they have to ultimately test their carbon capture and conversion technologies at either a coal-fired power plant or a natural gas-fuelled power plant.

The centre's 40,000 square feet of technology innovation space includes 28,000 square feet devoted to pilot plant development, along with 9,000 square feet of office space. There is also 2,500 square feet of wet chemistry laboratory space, an analytical room, chemical and gas cylinder storage, a machine shop and a tool room. The facility provides 720-kilowatt electrical service, 66 gallons-per-minute water supply and five megawatts of natural gas supply to the indoor and outdoor pilot plant areas.

Generally, CO2 conversion processes are divided into three very different categories:

• Biological processes where a biological organism rapidly absorbs CO2 and uses sunlight to produce a product;

• Chemical processes where a catalyst works to break carbon-oxygen bonds and then combines carbon with other elements to product a product; and

• Mineralization processes where CO2 reacts with other elements and is sequestered as a solid carbonate that can be incorporated into products.

CCCI's new centre will accommodate a number of different CO2 conversion processes, including chemical, electrochemical and thermal. On the carbon capture side, the centre will be able to handle current carbon dioxide capture technologies, which use amine or solvent-based systems, as well as novel capture technologies based on solid sorbents or membrane-type processes.

Teams choosing to utilize CCCI's centre will pay a fee for use. In addition to the new facility, Vlajnic says that CCCI offers semi-finalists "the ability to really answer their fundamental questions about their technology by the best researchers or subject matter experts from the University of British Columbia (UBC), which is also our partner."

UBC is critical in evaluating early-stage ideas, with a research team at the university's Department of Chemical and Biological Engineering and a multidisciplinary group at its affiliated Clean Energy Research Centre.

Two US$7.5-million grand prizes to be awarded

Launched in 2015, the NRG COSIA Carbon XPRIZE is sponsored by NRG, a U.S.-based power company, and by Canada Oil Sands Innovation Alliance (COSIA) of oil sands producers. The 4 ½-year competition is structured as a two-track prize, with finalists ultimately testing their CO2 conversation technologies at commercial scale at either an operating natural gas-fuelled power plant in the province of Alberta in Western Canada or an operating coal-fired power plant in the State of Wyoming in the United States.

To advance to the final round, teams must demonstrate a carbon dioxide conversion system at two to five tonnes CO2 per day throughput. A total of US$20 million will be awarded: US$2.5 million shared equally among up to five finalists in each track, and a US$7.5-million grand prize to each winner in each track. The two winning teams will convert the most CO2 into products with the highest net value while meeting strict environmental requirements for CO2 emissions, water and land use.

Nine of the semi-finalist teams are from Canada, while the others come from China, India, Switzerland, Scotland and the United States. The teams include innovative carbon capture technology companies, top-tier academic institutions, non-profits and new startups. They propose converting CO2 into products as varied as enhanced concrete, biofuels, toothpaste, nanotubes, fish food and fertilizer.

CO2 Solutions demonstration project capturing 10 tonnes per day of carbon dioxide (Image ©CO2 Solutions)

"We're excited by the diverse proposals from teams hailing from differing geographies," said Ben Trammell, senior vice-president engineering & construction at NRG. "Finding a viable and compelling solution for converted CO2 is an enormous task.

The XPRIZE attracts a diverse talent pool, too, which allows teams to bring groundbreaking ideas to the forefront."

"These teams perfectly represent the spirit, passion and promise that take us from problems to solutions," said Dan Wicklum, chief executive officer of COSIA. "By reimagining what can be done to turn CO2 into a multitude of useful products, the Carbon XPRIZE semi-finalists are poised to provide the world with solutions to positively address this challenge that we face today."

Canadian teams developing diverse technologies

The nine Canadian teams that have advanced to the semi-finalist round are:

CarbonCure Technologies Inc. – Led by Jennifer Wagner, vice-president sustainability, this team is based in Dartmouth in the province of Nova Scotia in Canada's Atlantic Maritimes region, and has a semi-finalist team with multiple partners. CarbonCure's technology is used in retrofitting concrete manufacturing plants to capture and recycle waste carbon dioxide to make stronger and more environmentally friendly concrete.

The technology injects recycled CO2 into wet concrete while it's being mixed; the CO2 becomes chemically converted to solid calcium carbonate minerals and permanently captured within the concrete. The technology is currently being used by more than 40 concrete companies in Canada and the United States. CarbonCure was named in the prestigious 2017 Global Cleantech 100, produced by Cleantech Group, and received the 2016 Manning Innovation Award.

Carbon Cure's technology control system installed at a concrete manufacturing plant (Image ©CarbonCure Technologies)

Worker preparing mixture of Carbon Cure's environmentally friendly concrete (Image ©CarbonCure Technologies)

Carbon Upcycling Technologies – Led by Apoorv Sinha, president, this company is based in Calgary, Alberta – one of two semi-finalists from the province of Alberta. The team uses a proprietary process that captures industrial carbon dioxide and joins it with graphite to create graphene nano-platelets. These nanoparticles can be used to making a lighter and stronger concrete, reinforce construction materials, increase electrical conductivity of plastics, produce water purification membranes, and manufacture high-performance electronics.

Carbicrete – Led by Yuri Mytko, this startup company founded by University of McGill graduates is based in Montreal, Québec – one of two semifinalists from the province of Québec.

The team's patented technology, which can be implemented in any concrete products plant, uses an industrial residue – the waste slag from steel-making factories – to replace cement as a binding ingredient in "carbon-negative" concrete construction blocks and other concrete products. The process injects carbon dioxide gas into the wet concrete to give it its strength, while permanently sequestering the CO2.

Carbon Electrocatalytic Recycling Toronto (CERT) – Led by Ted Sargent, professor of electrical and computer engineering, this semi-finalist is based at the University of Toronto in Toronto, Ontario – one of three semi-finalists from the province of Ontario.

The team is developing robust, efficient, nanostructured metal catalysts that use renewable electricity to turn CO2 selectively into useful fuels and high-value chemical feedstocks.

CO2 Solutions – Led by Louis Fradette, director, valorisation carbone (carbon value development) Québec, this team is based in the city of Québec.

The company's patented, non-toxic enzyme-accelerated solvent process – in essence an 'industrial lung' for carbon capture – captures carbon dioxide from effluent gases and produces pure CO2 for utilization. Potential applications for the CO_2 include in enhanced oil recovery, pulp and paper processing, water treatment, greenhouses, beverage carbonization and others, as well as CO_2 capture in oil sands production.

CO_2 Solutions has completed a demonstration project near Montréal, Québec, that captured 10 tonnes of CO_2 per day and the company is now entering commercial phase.

Ingenuity Lab – Led by nanotechnology expert Carlo Montemagno, professor of chemical and materials engineering and director of Ingenuity Lab, this semi-finalist is based at the University of Alberta in Edmonton, Alberta.

The team is developing nanoparticles to sequester carbon dioxide from industrial gas flue emissions and – by mimicking the biochemical reactions of photosynthesis – convert the CO_2 into energy-rich carbohydrate compounds for making high-value specialty chemical products.

Pond Technologies Inc. – Led by Peter Howard, vice president corporate sustainability, this team is based in Markham in the Greater Toronto area in the province of Ontario.

The company's technology uses the direct, untreated exhaust from industrial processes to grow algae, removing carbon dioxide, nitrogen oxides and sulphur dioxide while producing biodiesel and solid biofuel (biomass pellets) for heating.

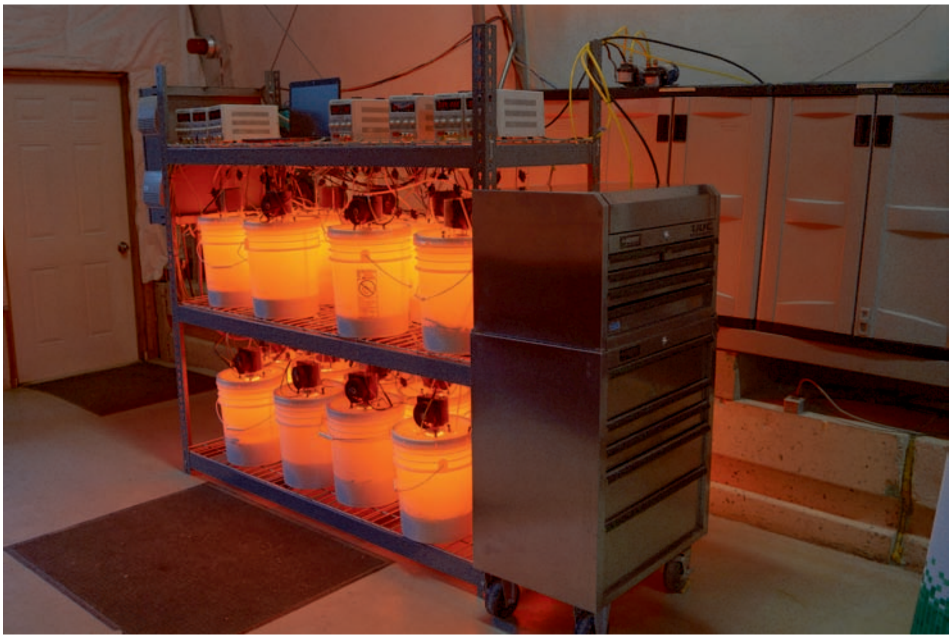
Tandem Technical – Led by Jerry Flynn, founder and CEO, this environmental engineering firm is based in Canada's capital city of Ottawa, in the province of Ontario. The team's patent pending carbon capture and utilization process aims to convert CO_2 into health supplements, toothpaste, paint and fertilizers.

Terra CO2 Technologies Ltd. – Led by Dylan Jones, CEO, British Columbia's only entry and semi-finalist is based in Vancouver. The company has developed a patented chemical process that converts and permanently sequesters carbon dioxide into a stable, non-toxic solid form (iron carbonates) that can be safely put back into the mining excavation or spread over the mine site.

The technology treats sulphuric acid rock drainage, a waste produced by mining operations, while producing saleable sulphur products. The company's primary market focus is the mining industry, which has problems with acid drainage runoff at many sites around the world.

However, a secondary market is any operation that has sulphide salts and is close to a CO_2 flue gas stream source, such as cement and fertilizer manufacturing sites.

Equipment for running incoming flue gas through a condenser (to eliminate water) and pressurize the gas in preparation for use in the 25,000-litre tank (Image ©Pond Technologies)



Pond Technologies' small bioreactors for testing different algae strains and running various experiments (Image ©Pond Technologies)

More information

Mark Lowey is the managing editor of EnviroLine and has worked as professional journalist in Calgary for more than 36 years.

cmcghg.com

www.xprize.org

CO2 Solutions' enzyme catalyst for cost-effective carbon capture

CO2 Solutions patented enzyme catalyst offers a cost-effective and environmentally friendly CO2 capture solution. A recent pilot study showed the potential for CO2 capture at a cost below $40/tonne - a larger demonstration project has received funding from the Alberta Government.

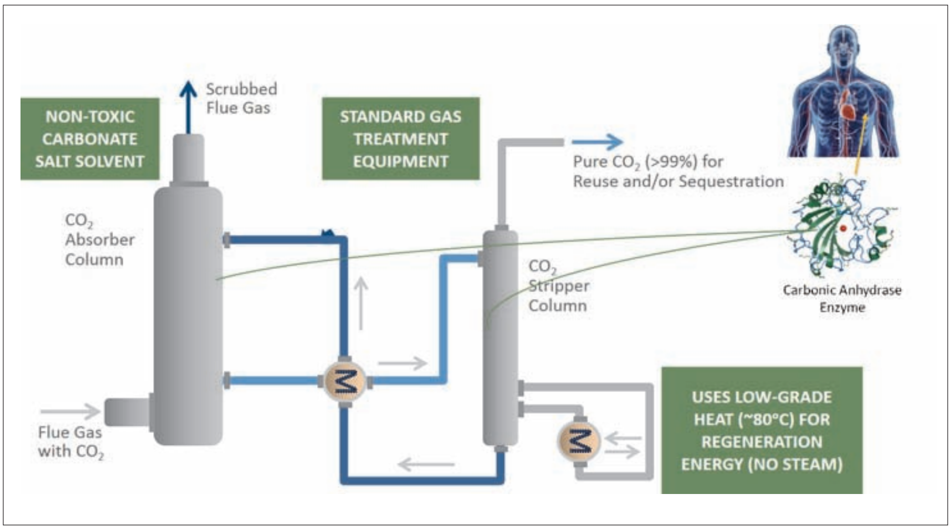
Canada's carbon dioxide (CO2 emissions) stood at 732 megatonnes (Mt) in 2014. Of this total, 262Mt, or 36% were from large stationary sources with annual emissions of greater than 50,000 tonnes1. This includes coal and gas fired power and steam plants, cement plants, oil refining and upgrading operations, aluminum production facilities, and other large industries integral to the Canadian energy and manufacturing economy.

As such, in the context of reducing Canada's greenhouse gas emissions in aggregate in line with the Government of Canada's national carbon pricing plan2, reducing CO2 emissions from these large stationary sources will be essential. At the same time however, it will be important to not put undue economic strains on these industries through the impositions of high mitigation costs.

One of the key solutions already recognized by the Government of Canada to the large source emissions challenge is carbon capture, utilization and storage (CCUS)3,4. However, conventional (amine) chemical carbon capture technology employed in the world's first large CCUS deployments is far too costly for broad deployment in Canada.

With a typical cost of $60-90/tonne-CO25,6, it is far above present carbon pricing being considered here and abroad. Additionally, amine solvents suffer from significant environmental issues including toxic aerosol emissions and waste products detrimental to the environment and human health, and which limit their practical utility as a large-scale carbon capture option7,8.

To meet this challenge, CO2 Solutions Inc. (CSI) of Quebec City has commercialized a new biotechnological carbon capture process with dramatically lower costs and no toxic wastes. The technology is built around the use of the powerful enzyme catalyst, carbonic anhydrase (CA), which efficiently manages carbon dioxide during respiration in humans and all other living organisms.



The CO2 Solutions process for capturing CO2 with its proprietary biological enzymes

Employing a salt water solution similar to seawater in combination with the enzyme, the result is an 'industrial lung' for carbon capture with low operating and capital costs using known equipment infrastructure that is also environmentally benign.

In 2014, CSI successfully completed initial industrial testing with funding from Alberta's Climate Change and Emissions Management Corporation (CCEMC). A larger pilot test was completed in January 2015 in partnership with the globally recognized Energy and Environmental Research Center (EERC) and support from the U.S. Department of Energy (DoE).

This work showed the potential for cost of capture of below $40/tonne, which would meet the DoE's 2025 cost target for new carbon capture processes.

Finally, in October 2015, CSI successfully completed a 2,500-hour pilot campaign near Montreal at the scale of approximately 10 tonnes-CO2 captured per day (tpd) in partnership with Husky Energy and supported in part by the Government of Canada's ecoENERGY Innovation Initiative.

In a first commercial project, CO2 captured from a pulp mill is being used in Serres Toundra's greenhouses

Independently verified results of this pilot further confirmed the potential for a cost at large scale of less than $40/tonne.

Based on the successful demonstration, the technology is now moving to commercial implementation. In August 2016, CO2 Solutions announced its first commercial agreement for the deployment of its process to capture up to 30 tpd from a softwood kraft pulp mill in Saint-Félicien, QC owned by Resolute Forest Products Inc., and the utilization of this CO2 by a large neighboring vegetable greenhouse owned by Serres Toundra Inc.[9]

Supported in part by Sustainable Development Technology Canada and Quebec's Technoclimat program, and scheduled for commissioning by the end of 2017, the project will provide tangible economic and environmental benefits by improving the performance of the greenhouse while at the same time reducing the carbon emissions of the pulp mill.

Additionally, CO2 Solutions was awarded $15 million from Emissions Reduction Alberta towards the larger deployment of the technology in Alberta at the scale of up to 300 tpd for carbon sequestration and utilization[10].

Not only does the CO2 Solutions technology provide a cost-effective solution to capturing carbon emissions from Canadian industry, but it also provides the ideal platform for the conversion of these captured emissions to new value-added products. By doing so, economic value and new industries can be created while at the same time reducing emissions.

For instance, by combining captured CO2 with hydrogen produced from renewable power, CO2 can be converted into low carbon fuels, chemicals and plastics, and even protein. With a $15 million investment from the Government of Quebec's Green Fund, CSI is embarking on this effort by demonstrating such processes which can be rapidly rolled out commercially[11].

In summary, CSI's technology is a breakthrough in the quest for cost-effective carbon mitigation which can significantly reduce climate change causing CO2 emissions while not damaging an economy still largely dependent on fossil fuels.

It positions carbon capture as a viable climate change tool and helps Canadian industry to successfully compete in an increasingly carbon-constrained world by reducing emissions and producing new 'green' products from these waste emissions.

The 10 tonnes per day pilot project in partnership wth Husky Energy has confirmed the potential for a CO2 capture cost at large scale of less than $40/tonne

Further information

A video of CO2 Solutions' pilot plant can be viewed at:

https://www.youtube.com/watch?v=H5PnUvr9e6E

Another video of the company's vision for the value-added capture and utilization of carbon can be viewed at:

https://www.youtube.com/watch?v=-E5b6KSjCQg.

More information

www.co2solutions.com

Technical potential for CO2 capture and geological storage in Saskatchewan

The existence of suitable geological conditions, availability of large industrial CO2 sources and the technical expertise for CO2 capture coupled with a wealth of geological data and knowledge that has been developed in Saskatchewan over decades of petroleum, mining and other activities, provide unique potentials for CCS in this Canadian province.

This study discusses the technical potential for CO2 capture and geological storage in Saskatchewan. Potential for capture from coal-fired electricity generation facilities as well as the geological storage potential in the province in terms of the technical feasibility for CO2 storage in the suitable locations throughout Saskatchewan along with an estimate of storage capacity in the province are discussed.

Three coal-fired power generation facilities in southern Saskatchewan including the Boundary Dam, Shand and Poplar River power stations are selected as the most suitable industrial sources for CO2 capture in this study. An estimate of the volumes of CO2 that technically can be captured at these facilities by post combustion capture is provided.

In terms of geological storage, south-eastern Saskatchewan contains deep saline aquifers in addition to several light and medium oil pools which offer great opportunities for CO2 Enhanced Oil Recovery (CO2-EOR) and CO2 storage. Moreover, CO2 can be used for enhance heavy oil production in certain pools of Western Saskatchewan.

Power Generation Unit	Boundary Dam Unit #3	Boundary Dam Unit #4	Boundary Dam Unit #5	Boundary Dam Unit #6	Poplar River Unit #1	Poplar River Unit #2	Shand
Unit Type	Sub-Critical	Sub-Critical	Sub-Critical	Sub-Critical	Sub-Critical	Sub-Critical	Sub-Critical
Coal Type	Lignite	Lignite	Lignite	Lignite	Lignite	Lignite	Lignite
Annual operating hours (hrs)	7,968**	7,968**	7,968**	7,968**	7,968*	8,568*	8,328*
Net Power output (MW)	139	139	139	284	291	291	276
Annual power generation (GWh)	1,107	1,107	1,107	2,263	2,318	2,493	2,299
CO_2 Emissions (Tons)	1,080,970	1,080,970	2,208,602	2,037,203	2,263,039	2,433,449	2,243,363
Potential CO_2 Capture Volume at 90% (Tons)	972,873	972,873	972,873	1,987,741	2,036,735	2,109,104	2,019,027
Total Capture Potential Volumes							
Boundary Dam Power Station	4.91 Million Tons						
Poplar River Power Station	4.22 Million Tons						
Shand Power Station	2.02 Million Tons						

Table 1 - CO2 Capture potential estimations for Coal-Fired Power Stations in Saskatchewan
**Based on the values provided by the Canadian National GHG Reporting Program (GHGRP)*
***The assumption was made that the Boundary Dam units 3,4,5 and 6 operate the same number of hours annually as the Poplar River Unit #1.*

Existing CCS projects in Saskatchewan:

Boundary Dam Coal-Fired Power Station in southern Saskatchewan is the site of the world's first commercial scale post combustion CO2 capture. It started in 2014 and is capable of capturing one million tonnes of CO2 per year from one of its power units.

This means reducing emission intensity of the power unit to levels that can be considered the lowest and cleanest compared to any fossil fuel-fired power generation unit in the world. The captured CO2 is pipelined to the nearby oil fields for CO2-EOR and also is injected into deep saline formations for storage.

At the present time in Saskatchewan, there are two commercial CO2-EOR and storage projects operating in the southeast oil fields of the province; one in Weyburn operated by Cenovus Energy Inc. and the other in Midale operated by Apache Canada Ltd.

The Weyburn project is not only Canada's largest CO2-EOR operation but also the site of the world's largest geological CO2 storage project. It started in 2000, and receives CO2 via pipeline from two sources; the Boundary Dam power station and also the coal gasification plant in North Dakota.

The Midale project began in 1984 as a pilot project and became a commercial scale CO2-EOR project in 2005. It also receives its CO2 via pipeline from the same gasification plant in North Dakota that supplies CO2 to the Weyburn project. These two CO2-EOR projects inject about three million tons (Mt) of CO2 annually.

There are currently a number of CO2 enhanced heavy oil recovery pilot projects underway in the Lloydminster area in western Saskatchewan where CO2 is being injected to investigate different flooding scenarios in heavy oils. Compared to the conventional oil reservoirs these reservoirs are shallower and thinner, and therefore they have not been used for CO2-EOR /CCS storage activities in the past.

There is also a deep saline storage project near the Boundary Dam power station in southern Saskatchewan called the Aquistore Project. It serves as a storage site for the captured CO2 at this coal-fired electricity generating facility. This project includes two wells; an injection well (3396 meters deep) designed for injection rates of 1600 tons/day and an observation well (3400 meters deep) to examine CO2 migration within the saline formation. This project is also performing as an industrial laboratory for CCS related research in Canada testing the state of the art injection, measurement, monitoring and verification technologies.

Technical Potential for Capture

In Saskatchewan, there are currently three coal-fired power plants including Poplar River, Boundary Dam and Shand. These three plants have total capacity of 1,530 MW and use Saskatchewan's abundant supply of lignite coal to generate electricity.

In addition to Boundary Dam (BD) unit #3 which is already equipped with a post combustion capture unit, BD units 4, 5 and 6, Poplar River unit 1 and 2, and Shand power station are considered in this study as suitable sources for CO2 capture. All of the selected power plants are conventional pulverized coal-fired and are located in southeast Saskatchewan. Capture capabilities similar to the BD unit #3 are assumed for all the power generating units considered in this study.

Table 1 summarizes the operation parameters and potential capture volumes for the three power stations. As shown in the table, there is potential for the capture of more than 11 million tons of CO2 annually from coal-fired power stations in Saskatchewan. The emissions were calculated using CO2 emission intensity of 976 tons per GWh of generation for sub-critical coal-fired power units.

Technical Potential for Geological Storage

In general, the geological storage for CO2 can be described as its injection into the suitable geologic formations that provide the conditions for its safe storage. This includes injection into deep saline formations, depleted oil and gas reservoirs, coal beds and salt caverns. In addition to the above mentioned geological storage options, CO2 enhanced oil recovery (CO2-EOR) operations that involve the injection of CO2 into the oil and gas reservoirs for production improvement purposes have also been proven to offer considerable capacity for safe CO2 storage.

Enhanced oil recovery projects provide great potential for safe geological storage as the geology of hydrocarbon reservoirs are generally well understood and the additional oil recovery can offset the costs. Deep saline aquifers are also among the most promising options for geological storage of CO2 because of their large storage volume potentials and frequent occurrence in geologic formations.

The injected CO2 will be trapped through a number of mechanisms, including physical, residual, solution and mineral trapping. In principle, it is desired to inject CO2 at sufficiently high temperatures and pressures to form the supercritical phase (CO2 will be in supercritical state at temperatures and pressures higher than critical values of 31.1°C and 7.38 MPa, respectively). This will cause more CO2 to be stored in the pore space of the rocks as the supercritical fluids have liquid like density.

This study only considers deep saline formations, depleted oil reservoirs and CO2-EOR operations for geological storage in the province. The storage potentials in each category have been identified through building a data base of the oil pools and saline formations using available information and then identifying the technically suitable options by screening them according to the appropriate criteria for each category. The data base comprises a significant number of oil and gas pools in different stages of development, as well as saline aquifers throughout Saskatchewan.

CO2-EOR Potential

CO2-EOR has been used in the upstream petroleum industry for a number of decades. It has primarily used CO2 found in natural deposits or captured from industrial sources. At the present time more than 3 billion cubic feet per day (about 65 million tons per year) of CO2 is being injected into the oil fields in North America.

In CO2-EOR, the associated storage of CO2 in the oil reservoir occurs as an inherent part of the injection and recycling operation. Approximately 45 to 55% of the injected CO2 becomes trapped in the geologic formation and remains in the reservoir and about 45 to 55% of it is co-produced with the oil and the naturally occurring gases which also include some CO2 that is native to the reservoir.

The recycling facilities that are usually installed as part of the CO2-EOR operations make it possible for the produced CO2 to be separated from the oil and gas prior to being re-injected into the oil field. CO2-EOR projects resemble a closed-loop system where the CO2 is injected, some of it is trapped in the formation, and the rest is produced along with oil and is recycled back into the reservoir.

There are several criteria for screening oil pools for CO2-EOR applications and geological storage, the most important of which are the depth and thickness of the formation, oil gravity, and residual oil saturation prior to CO2 injection. The Minimum Miscibility Pressure (MMP) between oil and CO2 is also an important factor for determining the suitability of an oil pool for CO2-EOR. The MMP itself depends on a number of oil and reservoir properties including oil composition, oil gravity, and reservoir temperature.

In this study, it was assumed that the injection pressure will be high enough to achieve the miscibility between the oil and CO2. All the oil pools considered in this work were sandstone or carbonate with depths greater than 2500 feet, oil gravities greater than 22 API, residual oil saturations higher than 20% PV, and the net thickness of 10 feet or higher.

The results of CO2-EOR operations in Weyburn and Midale oil pools in Saskatchewan show a projected incremental oil recovery of 11% and 17% of Original Oil In Place (OOIP), respectively. These values fall within the range suggested by many researchers in Canada and the US. Moreover, the amount of CO2 stored in the reservoir per barrel of incremental oil produced at Weyburn and Midale oil pools are 6.95 Mscf/bbl and 9.61 Mscf/bbl, respectively.

Based on these results and many previous studies done by different researchers (as listed in the Reference section of this report), a range of 7 to 23% of additional oil recovery from the CO2-EOR operations and an average of 8 Mscf per bbl for the CO2 storage capacity was used in this study for the oil pools in Saskatchewan.

The following equations were used to estimate the CO2 storage capacities:

$$M_{CO_2,\min} = OOIP \times 0.07 \times 8 \times 0.28316 \times \rho_{CO_2,s}$$

And

$$M_{CO_2,\max} = OOIP \times 0.23 \times 8 \times 0.28316 \times \rho_{CO_2,s}$$

where $M_{CO2,min}$ and $M_{CO2,max}$ are the minimum and maximum CO2 storage capacity based on 7% to 23% of the OOIP recoverable in million tons, respectively, OOIP is the original oil in place in million barrels, and ρ_{CO2} is the density of CO2 at standard conditions which is 1.977 kg/m3.

Area	OOIP (Million bbl)	CO_2 EOR potential (Million bbl)	CO_2 storage capacity (Million tonnes)
Screened Weyburn light oil pools	6,460	452–1,486	203–665
Screened Weyburn medium oil pools	2,288	150–526	72–236
Screened Swift Current medium oil pools	1,248	87–287	39–129
TOTAL	**9,996**	**689–2,299**	**314–1,030**

Table 2 - Summary of CO2-EOR potential and estimated storage capacity for the screened oil pools

Significant petroleum deposits in Saskatchewan are located in four major regions: Lloydminster, Kindersly-Kerrobert, Swift Current, and Weyburn-Estevan. A total of 473 oil pools in these regions were initially included in the database. Based on the applied screening criteria noted before, 239 oil pools were considered suitable for CO2-EOR applications, all of which are located in the Swift Current and Weyburn regions in the southern part of the province.

It must be mentioned that the depth of oil pools in Kindersly area is less than 734 m. In addition, all the oil pools in the Lloydminster region contain heavy oils (API < 18.24). Therefore the oil pools in Kinersly and Lloydminster regions were not considered in this study. The potential CO2 storage capacities for the screened light and medium oil pools in Weyburn as well as medium oil pools in the Swift Current area are summarized in Table 2 above.

Deep Saline Formation Storage

In case of saline formations, one of the most important selection criteria for geological storage of CO2 is the tectonic stability of the formation. Tectonic stability will prevent the creation of possible leakage pathways for the CO2 to escape from the aquitard. In addition, size of the saline formation should be large enough to provide considerable storage capacity. Depth of the formation is another important selection criterion which affects the state of the injected CO2 underground and in turn influences the overall storage capacity.

Only saline formations with depths greater than 800 m where the CO2 will be in the supercritical state are considered suitable for geological storage of CO2. Moreover, the potential formations must have sufficiently high porosity and permeability. Low porosity and permeability formations will limit the CO2 injectivity and as a result hinder the injection rate and storage capacity.

In saline formations, estimation of CO2 storage capacity strongly depends on the trapping mechanism(s) under which the injected CO2 will be stored. These trapping mechanisms act over different time periods which makes the capacity estimation challenging. In addition, the variable nature and heterogeneity of the geological formation and rock characteristics add to the complexity.

In 2008, the Carbon Sequestration Leadership Forum (CSLF) proposed a methodology to provide a consistent estimation of CO2 storage potentials in saline formations. The CSLF methodology was used in this study to evaluate the CO2 storage capacity in saline formations in Saskatchewan. Structural/stratigraphic, residual, and solubility trappings were considered in this study to estimate CO2 storage capacity as they are the main mechanisms that contribute the most to the CO2 storage capacity in saline formations.

It needs to be mentioned that mineral trapping is basically time dependent and evaluation of resulting storage capacity requires a detailed knowledge of the chemical reactions between the CO2 and reservoir rock and brine. The following relationship proposed by the CSLF was used in this study for calculating the CO2 storage capacity in saline aquifers within structural and stratigraphic traps.

$$M_{CO_2,st} = C_{st} \times A \times h \times \phi \times (1 - S_{wirr}) \times \rho_{CO_2}$$

where, $M_{CO2,st}$ is the CO2 storage capacity through structural/stratigraphic and residual trappings in kg, C_{st} is the trapping capacity coefficient which takes into account the effects of trapping heterogeneity, CO2 buoyancy, and sweep efficiency, A is the aquifer area in m2, h is the average aquifer thickness in m, φ is the average aquifer porosity in fraction, S_{wirr} is the irreducible water saturation after CO2 injection in fraction, and ρ_{CO2} is the density of CO2 in kg/m3.

In this report, a value of 0.2 for both the areal and vertical sweep efficiencies and 0.25 for the reservoir heterogeneity factor are considered which results in C_{st} = 0.01. In addition, the irreducible water saturation was calculated based on the following equation by using the average porosity and permeability data for each aquifer:

$$S_{wirr} = 5.6709 \times [\log(k)/\phi]^{-1.6349}$$

On the other hand, the CO2 storage capacity through solubility trapping can be obtained from the following equation as suggested by the CSLF task force:

$$M_{CO_2,sol} = C_{so} \times A \times h \times \phi \times \chi_{CO_2}$$

Where, $M_{CO2,sol}$ is the CO2 storage capacity by solubility trapping in kg, C_{so} is the solubility trapping capacity coefficient to consider the effects of all factors that govern the volumetric spread and dissolution of CO2 into the formation brine, and χ_{CO2} is the solubility of CO2 in the aquifer's brine under reservoir conditions in g/L. In general, the dissolution process takes place over a period of time which may vary depending on the brine salinity, aquifer temperature and pressure conditions, as well as the reservoir petrophysical properties including porosity and permeability.

Deep saline aquifers in Saskatchewan occur in different formations in southern and southwestern parts of the province. In this study a total of seven aquifers were considered as suitable targets for geological storage of CO2. These formations were selected based on their depth (more than 800 m, since normally CO2 reaches supercritical state at depths higher than 800 meters) and sealing ability (overlaid by impermeable aquitards). In addition they have sufficiently fair porosity and permeability which ranges from 13 to 33% and 10 to 350 md, respectively.

To estimate the CO2 storage capacity based on the CSLF methodology used in this study, the required information including the aquifer surface area, thickness, porosity, irreducible water saturation after CO2 injection, CO2 density and its solubility in formation brine under different conditions of pressure, temperature and brine salinity were taken into account. In this study, it was assumed that aquifers are under hydrodynamic equilibrium and values of 10.516 kPa/m and 25°C/km were used to obtain the temperature and pressure profiles, respectively, at different depths to the top of each formation.

The estimated CO2 storage capacities for each saline formation as well as the total capacity for all the formations are summarized in Table 3.

Depth interval (m)	Accumulative CO_2 storage capacity in seven different geologic formations (Million tonnes)						
	Deadwood	**Ordovician-Silurian**	**Winnipegosis**	**Souris River**	**Birdbear**	**Jurassic**	**Mannville**
800-1000	887	203	661	932	1,265	846	600
1000-1200	2,157	585	835	1,393	1,055	1,456	902
1200-1400	1,783	372	948	1,973	1,221	234	123
1400-1600	2,284	479	1,158	1,462	1,320	-	-
1600-1800	3,744	516	1,426	1,516	1,933	-	-
1800-2000	3,549	328	787	2,385	639	-	-
2000-2200	2,929	500	1,450	670	292	-	-
2200-2400	2,938	182	405	498	191	-	-
2400-2600	1,240	85	246	124	-	-	-
2600-2800	943	42	80	-	-	-	-
2800-3000	631	-	-	-	-	-	-
>3000	246	-	-	-	-	-	-
TOTAL	**23,331**	**3,292**	**7,996**	**10,953**	**7,916**	**2,536**	**1,625**
TOTAL estimated storage capacity for all formations							**57,469**

Table 3 - Estimated CO2 storage capacities for each saline formation as well as the total capacity for all the formations

Conclusion

CCS is globally recognized as an effective technology for reducing GHG emissions from large industrial sources. Extensive oil pools and saline aquifers occurring at different locations throughout Saskatchewan provide a great potential for geological storage of CO2. More specifically, huge light and medium oil pools in the Weyburn and Swift Current regions in southern Saskatchewan have a significant potential for CO2 enhanced oil recovery and geological storage. In addition, Saskatchewan contains several deep saline aquifers which can be considered as potential CO2 storage.

In terms of the estimated storage capacity, saline aquifers provide significantly higher values compared to EOR projects. This is mainly due to their extremely large volumes and depths. In addition, it is estimated that significant amounts of CO2 can be stored inside Saskatchewan's oil pools while enhancing hydrocarbon production from those pools. The total technical geological storage potential in Saskatchewan is estimated to be between 57,783 and 58,499 million tons.

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Climeworks captures CO2 directly from the atmosphere

Climate change is being driven by human activities. In order to slow its progress, the global community urgently needs 'negative emissions technologies'. This was once again clearly and urgently shown to be the case during talks at COP22 in Morocco. The technologies in question have to be mature and economically viable. Climeworks is a leading global contender here with its Direct Air Capture technology.

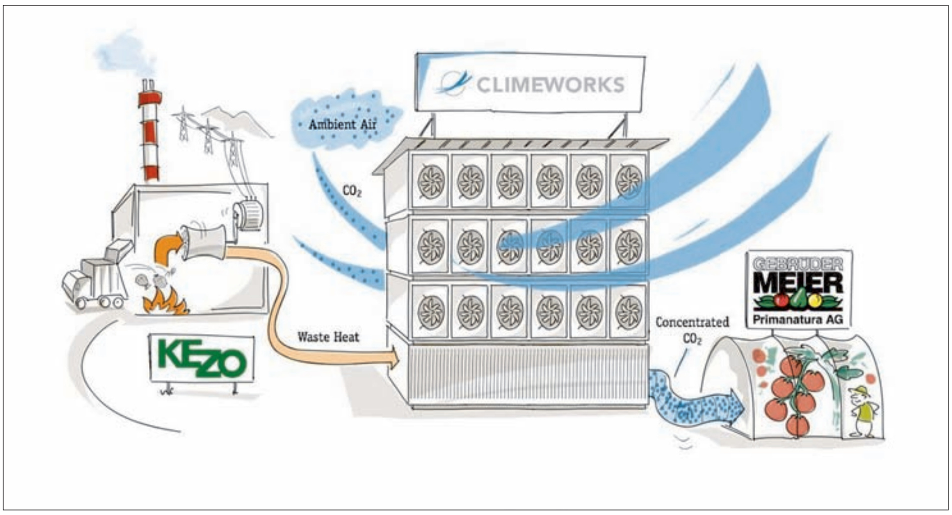
Climeworks is a cleantech company based in Zurich, Switzerland. Founders Christoph Gebald and Jan Wurzbacher have been working on their vision to close the carbon dioxide cycle and stabilise global CO2 emissions since 2009. In November 2016, the company was in Morocco for COP22 where it presented its solutions to several hundred decision-makers from the worlds of politics and economics. This year, Climeworks is facing a number of key milestones on the journey to commercialising its own technological approach.

Climeworks' technology is a kind of CO2 vacuum cleaner that extracts the gas directly from the atmosphere. The air is sucked in by a fan and then blown through a filter element. Sensors detect when the filter is full. This usually takes between two and three hours. The filter is then regenerated by heating it to 95 degrees Celsius. The CO2 and moisture that have been captured are released during this process. The CO2 is extracted and creates a high-purity product that can be marketed for a wide range of applications.

Recyclable filter

"The filter is, of course, re-used many times and lasts for several thousand cycles," reveals Wurzbacher. The rest of the 'Direct Air Capture' technology is made of steel and processed components that can be used for many years. The filter material was originally developed in close collaboration with the ETH Zurich and the Swiss Federal Laboratories for Materials Science and Technology (EMPA).

The Climeworks team then went on to refine the technology further. One of the filter materials that was developed is made of cellulose, which "works like a sponge due to its large surface area," explains Wurzbacher. The cellulose is modified with amines, which bind the CO2 in conjunction with the moisture in the air. This bond is dissolved at temperatures of around 95 degrees.



A Climeworks installation and a schematic of the process

A key benefit of the cellulose material is that it is cheap to source and can also be easily disposed of as biomass. "We have over 500 material samples stored in our lab," reports Wurzbacher. Further research is being carried out to bring down costs and raise efficiency levels even more.

2017 milestone: First commercial plant

The team at Climeworks has grown to 40 people and they have set themselves a particularly important goal for 2017: The company wants its first commercial CO2 capture plant to go on stream during the first half of the year in the town of Hinwil (Switzerland). This plant will then filter 900 tons of CO2 out of the atmosphere per year and feed it into a nearby greenhouse. Eighteen collectors and four forty-foot containers will be required for this. "The first plants will cost between one and two million euros," explains the Managing Director.

Climeworks' CO2 extractors use a recyclable filter and can easily be scaled up

The conditions on-site in Hinwil are perfect for the plant. The containers will be positioned on the roof of a waste incineration and processing plant. This facility will provide the thermal energy to power the modules. A large greenhouse operator is also located close to the site and will use the captured carbon dioxide to enhance tomato and lettuce growth.

Until now, the CO2 had to be transported long distances by truck to the site. The Climeworks modules will supply fresh CO2 around the clock from mid-2017 on. Adding CO2 in this way ensures a consistent concentration inside the greenhouse, which, in turn, increases plant growth by up to 30 percent.

The cost benefits compared to conventionally produced CO2 vary significantly from region to region. "Market prices fluctuate greatly and lie between 100 and several hundred euros per ton," elaborates Wurzbacher. In Germany, for example, there is a steady supply of CO2 across the country from ammonia production. This means that market prices are low. "However, the situation is very different in many other regions of the world. On islands, for example, CO2 has to be shipped in via difficult routes."

Opening up new markets

Using CO2 as a raw material for carbonating mineral water and soft drinks is another interesting application for the cleantech company. "Our CO2 is produced de-centrally to extremely high purity levels and is therefore particularly beneficial for hygiene-sensitive sectors," reports Valentin Gutknecht from Climeworks. From their talks with the drinks industry, the Climeworks managers know that in this sector too the ability to produce CO2 on site using ambient air is also a particularly interesting option for more isolated locations.

In the food sector, CO2 is used for safely packaging fresh meat and vegetables as it prevents bacteria from forming and stops oxidation. CO2 can also be used as dry ice for transport purposes.

Power-to-liquids with atmospheric CO2

Using carbon dioxide in climate neutral fuels, however, would have a much greater impact on the problem of climate change. In Dresden, Climeworks partner Sunfire has been testing the viability of creating synthetic fuels from water, green energy and CO2. Premium car manufacturer Audi has already taken the first three tons of this synthetic fuel. The synthetically produced alternative fuel is much more environmentally friendly than its conventional counterparts. It has a CO2 savings potential of between 30 and 85 percent.

"Sunfire and Climeworks' technologies fit very well together and we have been developing them in close collaboration for years," continues Wurzbacher. "We need waste heat to be particularly efficient and Sunfire produces excess steam".

It remains to be seen if, this year, the political landscape will change sufficiently for this alternative fuel to be accepted as a viable alternative – one that does not compete with food production and can be generated entirely in the respective manufacturer's region. "We hope that Switzerland will position itself as a leader here compared to other European countries," explains Wurzbacher.

Generating negative emissions

Climate conferences in past years and IPCC reports have clearly shown that, on its own, reducing CO2 emissions will not be enough to meet the 1.5-degree goal set by the global community in Paris. "In order to capture CO2 from the atmosphere continuously and on a large scale, the price per ton of carbon dioxide has to be less than 100 euros," explains Wurzbacher. "Our goal is to come in below this crucial threshold". To achieve climate goals, the world needs to take a combined approach comprising on the one hand, an aggressive reduction of emissions and, on the other, technologies capable of capturing CO2 retroactively from the atmosphere.

One of the key benefits of Climeworks' technology is that it is easily scalable and does not require any water, only electric or thermal energy, which can be produced, for example, from solar thermal energy and photovoltaics.

"Of course, we would need a large area to install 25,000 containers in the future. But due to the nature of this technology, we can do this in areas with very little natural vegetation, for example in deserts close to the equator and combine this with underground storage there," adds Wurzbacher. "After all, it doesn't matter where we take CO2 from atmosphere. What's important is that we do it as cost-effectively as required and with as little impact as possible".

More information

www.climeworks.com

A roadmap for CCS in Australia

An independent report commissioned by government, industry and research organisations has laid down a comprehensive plan for CCS deployment in Australia as an option for achieving emissions reductions in a timely manner.

The report 'A Roadmap for Carbon Capture and Storage' was led by Professor Chris Greig of the University of Queensland and involved a steering committee comprising the Commonwealth Government, NSW Government, CSIRO, CO2CRC Limited, ACALET (COAL21 Fund) and ANLEC R&D.

"Australia's continued economic prosperity and competitiveness depends on access to all forms of energy and strong industries. We need to deal with the mitigation of greenhouse emissions from these activities and prudent early planning relating to CCS deployment is a priority," said Professor Greig.

Tania Constable CEO of CO2CRC Limited said "A technology neutral policy approach is necessary to achieve reliable, available 24/7, clean energy in Australia. We would like to see ARENA and the Clean Energy Finance Corporation's mandate opened up to include a range of carbon reduction technologies including carbon capture and storage."

Dr Peter Mayfield of CSIRO said "The transition to a low carbon energy system is a significant and delicate challenge that will require the full range of options to achieve a sustainable future energy mix that also meets the standards of reliability, stability and affordability required. We see CCS as one of a number of key technologies required to meet that challenge during transition and into the future."

Greg Evans CEO of ACALET (COAL 21 Fund) said "It's important we have reliable and low cost energy provided by coal fired generation and we maintain our competitive large scale energy intensive industries. That means HELE technology and CCS to provide emission reduction options, this Roadmap shows us the way to achieve that."

More information

www.co2crc.com.au

Key messages

1. Deployment of Carbon Capture and Storage (CCS) is vital to Australia's long-term economic prosperity and energy security.

2. CCS must be available on its merits in Australia's energy mix to assure energy system security and affordability so that future emissions reductions targets are delivered at the lowest economic cost.

3. CCS is required beyond use in the power sector as it will play a vital role in decarbonising energy intensive industries, which involve the continued use of fossil fuels.

4. CCS is not an experimental technology. It is being deployed or available now at commercial scale to:

- provide a competitive, carbon reduction option for reliable 24-7 power from fossil fuels.
- decarbonise a number of existing and prospective emissions-intensive industries including natural gas and LNG production, iron and steel making, cement production, fertilisers, chemicals and textiles.

5. The deployment of CCS globally is critical for Australia's trade balance and jobs that underpin coal and gas exports.

6. Leadership in CCS could enable new industrial production in Australia and provide an opportunity to increase competiveness and create jobs in high value adding sectors, while achieving emissions reduction targets.

7. Urgent early investment in CCS is required to assure that CCS can be deployed to achieve the deep reduction in greenhouse gas emissions required to achieve national and global targets.

8. The Roadmap is a call for significant additional funding for CCS Research, Development and Demonstration (RD&D) from Government and Industry.

9. Government and Industry should consider significant ongoing investment in CCS for:

- CO2 storage characterisation
- Legal and regulatory capacity
- Monitoring international CCS deployment
- Techno-economic assessments
- Engagement to achieve public acceptance. Such investments may require CO2 storage demonstrations.

10. The Australian Government currently has a range of energy security and climate change reviews planned or in progress. CCS must be one of the technologies considered in such reviews.

UK Government critical of CCS failure

The Department for Business, Energy & Industrial Strategy did not achieved value for money for its £100 million spend on the second competition for government financial support for carbon capture storage, according to the National Audit Office.

The Department also spent £68 million on the first competition on support for CCS, which it cancelled in 2011. Today's report found that the Department's plan to use a second competition to develop and deploy carbon capture and storage was ambitious, but ultimately, unsuccessful.

Achieving this goal was challenging because the untried nature of the technology meant the costs and benefits of the proposed projects were inherently uncertain, said the NAO. Given the level of challenge, it was an achievement for the Department to sustain negotiations with the preferred bidders to the point where it gained valuable technical and commercial knowledge about how to deploy the competition projects. But any value that could be gained is contingent on the Department applying the lessons it and the sector has learnt as a result of the competition.

The NAO found the Department began the competition without agreeing with HM Treasury on the amount of financial support available over the lifetime of the projects. This ultimately contributed to HM Treasury's decision to withdraw £1 billion of funding from the competition, leading to its cancellation, as it was concerned about future costs to consumers. The Department had, however, designed the competition so it could withdraw from supporting its preferred bidders without incurring cancellation costs.

The terms of the competition contributed to one of the two shortlisted projects being unlikely to reach the construction phase. The Department funded two developers to undertake work that would reduce the commercial and technical risks surrounding the construction of the first CCS plant.

One of the two shortlisted projects, backed by a consortium, was not able to present a proposal compliant with the Department's risk allocation as it was struggling to allocate risks between the parties involved. The other competition was more commercially viable but would have had fewer benefits for reducing the costs of subsequent CCS projects.

"The Department has now tried twice to kick start CCS in the UK, but there are still no examples of the technology working," said Amyas Morse, head of the National Audit Office. "There are undoubtedly challenges in getting CCS established, but the Department faced an uphill battle as a result of the way it ran the latest competition.Not being clear with HM Treasury about what the budget is from the start would hamper any project, and caused particular problems in this case where the upfront costs are likely to be high. The Department must learn lessons from this experience if it is to stand any chance of ensuring the first CCS plants are built in the near future."

Many stakeholders think the government needs to carry more risk if it is to enable CCS to be deployed affordably to consumers. The Department's approach to allocating risk was in line with wider energy policy. But following the competition, many stakeholders think the government should bear more risks, particularly over stored CO2. Government taking a greater share of the risk could reduce delivery costs but would expose taxpayers to losses in the event of risks materialising. The NAO found that flaws in the Department's design and implementation of its Levy Control Framework, which caps the costs of certain consumer-funded policies, also impacted on CCS investors' confidence.

In developing the next phase of CCS, the NAO recommends that the Department should maximise the potential value from the competition by incorporating into its new CCS strategy the lessons it and the key stakeholders have learned.

The Carbon Capture and Storage Association (CCSA) welcomed the report, saying that the overarching conclusion was that the Government should develop a new CCS strategy, maximising the potential value from the cancelled competition by incorporating the lessons learned.

"It is important to remember that the ultimate reason why the competition was unsuccessful was because the promised funding for CCS was withdrawn at the Spending Review. If that had not happened then there is every reason to believe that the UK could now be building its first CCS project," said Dr. Luke Warren, Chief Executive of the CCS.

The CCSA has also formally endorsed the key conclusion from the report of the UK Parliamentary Advisory Group on CCS (September 2016); the first CCS projects in the UK can be developed at a cost of below £100 per MegaWatt Hour, under the right conditions.

"Our new analysis supports a key conclusion of the government-commissioned report by Lord Oxburgh that by building on the lessons from the CCS competition and taking a new and innovative approach to the design of a CCS delivery programme, CCS projects in the power sector can be cost-competitive with other low-carbon technologies from day one," continued Dr. Warren.

"The Committee on Climate Change have estimated that CCS can halve the cost of meeting the UK's climate change targets. The UK now needs to catch up with other countries that have successfully developed projects, and come forward with a new approach to CCS that recognises its tremendous value to decarbonising industry, heat and power - delivering a truly sustainable industrial strategy for the UK."

Professor Stuart Haszeldine, University of Edinburgh and SCCS Director, said, "What the UK needs now is a joined-up government company to act as contract owner and manager, but not operator, of CCS from CO_2 collection to transport and offshore storage. If the UK fails a fourth time then both Norway and the Netherlands are poised to dominate this big European growth business, which was invented in the UK but not built here."

More information

nao.gov.uk

ZEP - future CCS technologies report

The European Zero Emission Technology and Innovation Platform (ZEP) has released a report analysing emerging CCS technologies in the light of the 2030 targets set out in the Paris climate change agreement and suggesting processes and systems that, under specific criteria, appear promising compared to benchmarks.

In December 2015 at the Conference of the Parties (COP21), the world agreed to set an ambitious target: to limit the increase of the global average temperature to well below 2˚C, and pursue efforts to limit the temperature increase to 1.5˚C above pre-industrial levels, says the ZEP report "Future CCS Technologies."

Carbon capture and storage (CCS) is an essential element of the portfolio of measures needed to reduce greenhouse gas emissions. Without CCS, the cost of reaching the COP21 targets will increase by about 40%. In the past decade, the European Commission and/or Member State governments funded large incentive programs set up in Europe. A number of financial instruments have been established to support projects throughout different stages of development. However, these have not produced a single, operational, large-scale CCS demonstration project to date. The two operational CCS projects in Norway remain the exception.

Until recently, CCS efforts were mainly targeted at reducing greenhouse gas emission from the power sector, where some of the largest emissions points are found. The past few years have seen significant changes in this sector in Europe: increased penetration of renewable energy, a rapid phase-out of coal-fired power plants in several Member States, a fuel switch from coal to gas and the emergence of nuclear power in Member State plans for medium-term reform of the energy system. This has led to a highly uncertain basis for the development of CCS-based emission reduction in the power sector in the short term, which is exacerbated by CO2 emission prices that are not expected to increase significantly before 2025.

Making the environmental target set in COP 21 more stringent than the previous 2˚C, strengthens the case for a need of deep-cut technologies such as carbon capture and storage, as deep reductions are needed not only in the power sector, but also for the industry, where decarbonisation options are limited. Greenhouse gas emission reduction from carbon-intensive industries is likely to depend on carbon capture as fuel switch is often not an option, or process related emissions cannot be avoided. Meeting the national emission reduction targets by 2030 will rely heavily on reducing emission from these carbon-intensive sectors, such as steel and refineries.

"Our overview of technologies and analysis shows that CCS is ready for immediate implementation, thus, it is essential that current first-generation technologies are tested in actual CCS projects, to subsequently enable emerging techniques to progress."

The report also identifies knowledge and experience gaps to be addressed in order to advance and bring currently emerging technologies to the market, helping to decrease the cost of CCS. While essential, this is not by itself expected to lead to commercially available capture and storage technology in the short term. With emission price levels not likely to exceed the cost of CCS in the short or medium term, there will be no commercial business case for CCS until probably at least a decade from today.

Therefore, EU Member State governments will have to work hand in hand with the EC to enable a market for CCS, to ensure that CCS becomes a commercially viable solution for CO2 emission reduction, including negative CO2 emissions by biomass combustion. The reform of the European Emissions Trading System (EU ETS) is ongoing, and a market stability reserve is to be established as of 2018.

At the moment it is unclear how the reform will impact carbon price, so measures taken should include additional incentive programs and even government-coordinated CCS operations. The goal should be a stable and positive regulatory environment, in which CCS can deliver its promise of cost-effective, deep cuts in greenhouse gas emissions. Where possible, benefits from CCU - carbon capture and utilization - should also be exploited.

In parallel, research and innovation (R&I) efforts are required to continue towards CCS cost reduction and applicability across power and industry sectors. This report provides an overview of the state-of-the-art of CCS technologies, covering capture, transport and storage.

The assessment of future CO2 capture technologies carried out in this report has embraced not only the changing market conditions in power generation, but also the emerging importance of CCS for non-power industries. Furthermore, the assessment criteria of CCS technologies have been deliberately enlarged beyond typical cost and efficiency: assessment criteria incorporate key factors like operational flexibility, retrofitability, HSE issues, materials availability etc. in qualitative form.

Table 1 exhibits the improvement potential for emerging separation processes for CO2 capture compared to benchmark, today's 1st-generation demo plants, with regards to assessment criteria. In this table, only processes with Technology Readiness Level (TRL)>4 have been considered. Green colour indicates improvement potential. Yellow indicates indifferent, same or similar level and red means worse (or very uncertain) than benchmark. Yellow/green means that it could be better, but in the worst case is similar to the benchmark.

The table juxtaposes, in a qualitative way, the various emerging capture technologies according to the different assessment criteria introduced in this report. These will likely determine the economic viability and acceptability of the different CCS process options in a future CCS technology market.

As far as transport and storage is concerned, requirements for improvement of currently available technologies and, where the need was identified, the development of new technologies, were derived from the projected growth of CCS. This growth will lead on from current demonstration and early commercial projects that can be classified as one-on-one projects, to increasingly interconnected transport and storage systems, in which economies of scale are obtained by sharing transport and storage structures.

Capture

Isolated improvements are expected to have an impact on the overall efficiency penalty and cost of CCS systems. However, technology improvements arising from R&D works need to also be assessed on system (plant) level.

Current solvent based capture processes are commercially available but there is a substantial scope to reduce their cost and efficiency penalty. They also display limited operational flexibility, which is increasingly required by power plants. The development of capture processes allowing for (higher) operational flexibility (load following operation) without additional cost is therefore a key R&D challenge. Flexibility is a key requirement for the transport and storage elements of the CCS chain (i.e., variable supply of CO2) as well.

Process	Solvent based processes	Solid sorbent processes	High temperature solid looping systems		Membrane systems		
Separation Technology / Assessment criteria			Chemical looping	Calcium looping	Polymeric (post)	Ceramic (Oxy)	Metallic (pre)
Cost CAPEX							
Cost OPEX							
Efficiency penalty (thermodynamics, T- and P- level)							
Degradation solvent, sorbent, membrane							
Operational flexibility (on/off)							
HSE (waste, toxicity)							
Retrofitability[3)]							
Materials availability (abundance, manufacturing chain)							
FOAK cost							
Applicability, most suitable to	Power, NG processing, Steel, Refineries, other	Power (pre combustion), Steel, Refineries	Power (solid fuels), Refineries	Power (post combustion, solid fuels), Cement	Power, NG processing, Cement, Steel	Power (oxy and pre combustion)	Power (pre combustion), Refineries

Table 1 - Traffic light table of improvement potential for emerging separation processes for CO2 capture (process with TRL>4 only) compared to benchmark, today's 1st-generation

Transport

Transport of CO2 by pipeline is a well-established technology and is commercially available. R&I should focus on modelling transient flow phenomena in pipelines, across platforms and into wells, taking into account recent advances in the knowledge on the effects of impurities in the CO2. In transport networks, the management of CO2 quality becomes an issue, where mixing of streams of differing quality could affect the performance of the system. The required knowledge about the relationship between CO2 quality and the behaviour of the CO2 in the system has advanced considerably in recent years, allowing CO2 quality effects to be taken into account.

Ship transport of CO2 is also an established technology, but for large-scale CCS ship transport it needs to be scaled up. CO2 carriers exist, but larger ships will be required; the same can be said about loading and unloading facilities at ports. Offloading offshore, near the injection location requires some technology development and demonstration, such as flexible hoses and mooring systems. The effect of batch-wise injection, which may be the result of ship transport, on injection wells needs to be investigated.

Storage

The required operational flexibility holds for the whole CCS chain including CO2 injection and storage, in particular in the early stages of CCS development from demonstration to early deployment where the dependence on single sources for a reliable continuous supply will dominate availability of CO2. Systems analysis of the whole chain is necessary to evaluate where the capacity for flexibility is to be built most cost-effectively, e.g. flexible, cost-effective capture technology, in buffering and in networking to stabilize transport grid and storage load.

Research including full-scale demonstration is required on expanding the operational envelope of injection wells and subsea equipment under repetitive cycles of pressure and temperature changes, particularly for injection into low pressure stores like depleted pressure gas fields.

Approaches for effective storage portfolio management are necessary to efficiently exploit the available pore space, e.g. in large areal extent aquifers, to shorten the appraisal lead time and for timely expansion of the infrastructure for injection of CO2, including mothballing of existing infrastructure. Pressure management could support optimising the use of pore space, e.g. by using water production wells; research could be directed to strategies for water production, the breakthrough of CO2 and water treatment.

Developing lower-cost and storage specific monitoring and mitigation technologies remains an R&I target. Technology development should also be directed to less invasive leakage mitigation techniques and cost-effective methods for closing wells.

CCS systems

Incremental improvements in technologies of CCS chain elements can be obtained, but significant advances will only be made through operational testing and eventually commercialization. Emerging technologies depend on the operational use of existing technologies for their advancement, using market pull to develop lab, pilot and demonstration scale testing.

More information

Download the full report:

www.zeroemissionsplatform.eu

Projects and policy news

Petra Nova project construction completed

www.nrg.com

NRG Energy and JX Nippon Oil & Gas Exploration Corporation have completed construction of Petra Nova, the world's largest post-combustion carbon capture system.

The Petra Nova project at the WA Parish power plant in Texas will capture CO2 from the flue gas of an existing coal generating unit (Image ©NRG Energy)

The construction was completed on budget and on time.

Petra Nova first captured carbon dioxide (CO2) on September 19, 2016 and has delivered more than 100,000 tons of captured CO2 to the West Ranch field through an 80-mile pipeline. Final performance acceptance testing on the facility was completed on December 29, 2016 and the facility turned over for operations.

During performance testing, the system met all performance criteria including capturing more than 90% of CO2 from a 240 MW equivalent slipstream of flue gas off an existing coal-fueled electrical generating unit at the WA Parish power plant in Fort Bend County, southwest of Houston. At this level of operation, Petra Nova can capture more than 5,000 tons of CO2 per day which is the equivalent of taking more than 350,000 cars off the road.

"Completion of the Petra Nova project is an important milestone in our quest to help ensure reliable, affordable and increasingly cleaner energy from fossil fuels," said Mauricio Gutierrez, President and CEO of NRG Energy. "This project represents another major step in NRG's effort to reduce our carbon emissions and create a more sustainable energy future, and we are proud that this accomplishment was achieved on-budget and on-schedule in a competitive energy environment."

"I want to thank our partners at JX Nippon, Hilcorp and the U.S. Department of Energy as well as the State of Texas, our contractors and lenders for their commitment to the successful completion of this landmark project."d operations commencing as planned, thanks to the great effort made by the Petra Nova team."

Construction on the Petra Nova project began in 2014 with a goal to be operational by the end of 2016. With construction completed, on-budget and on-schedule, the Petra Nova carbon capture facility has achieved this goal.

"NRG and JX Nippon's Petra Nova is the type of innovative, technologically advanced project that proves time and again that Texas is the world leader in energy innovation," said Greg Abbott, Governor of the State of Texas.

Hilcorp Energy Company (Hilcorp), the operator of West Ranch oilfield, will use the captured CO2 to boost production at West Ranch oilfield, jointly owned by NRG, JX Nippon and Hilcorp. Both Hilcorp and the University Of Texas Bureau Of Economic Geology will monitor the movement of CO2 deep in the oil reservoir. Over the next few years, oil production at the field is currently estimated to increase from approximately 300 barrels per day before beginning Enhanced Oil Recovery (EOR) operations to production of up to 15,000 barrels per day using captured CO2.

"To date we have drilled nearly 100 new wells in the West Ranch field and have implemented a robust CO2 and ground water monitoring program," said Jeffery D. Hildebrand, Chairman and CEO of Hilcorp Energy Company. "We are excited about this project, and expect to see a meaningful increase in oil production at West Ranch in the near future."

Petra Nova is 50-50 joint venture by NRG and JX Nippon. Additionally, the United States Department of Energy (DOE) is providing up to $190 million in grants as part of the Clean Coal Power Initiative Program (CCPI), a cost-shared collaboration between the federal government and private industry. A portion of the project was financed with project loans from the Japan Bank for International Cooperation (JBIC) and Mizuho Bank, backed by Nippon Export and Investment Insurance (NEXI).

Petra Nova uses the KM-CDR Process®, jointly developed by Mitsubishi Heavy Industries, Ltd. (MHI) and the Kansai Electric Power Co., Inc., and employs a proprietary KS-1 high-performance solvent for the CO2 absorption and desorption. The carbon capture facility was constructed under a fixed-price contract by a consortium of Mitsubishi Heavy Industries Americas, Inc. (MHIA) and TIC (The Industrial Company). At peak construction, over 500 people were working on the project.

By being built on an existing coal unit, Petra Nova shows an economic path to make existing and new fossil fuel plants significantly more environmentally viable as we transition to more sustainable energy future.

Adoption of ETS Report is Crucial for CCS

www.zeroemissionsplatform.eu

The European Zero Emissions Technology & Innovation Platform (ZEP) believes that an ambitious ETS reform is indispensable for both EU climate policy and the continued support for Carbon Capture and Storage (CCS) in Europe.

The European Parliament has adopted its position on the EU Emissions Trading System (ETS).

Commenting on the vote, Dr. Graeme Sweeney, Chairman of ZEP, said:

"Today's vote is a step towards a more robust EU ETS, with a carbon price that can drive low-carbon innovation. It sends a signal that Europe is serious about meeting its long-term climate goals.

CCS is one of the climate technologies needed for the EU to contribute to the implementation of the Paris Agreement. The IPCC have concluded that it will be almost impossible to remain within the 2°C limit without CCS and that attempting to do so could increase the cost of tackling climate change by 138%.

But time is of the essence. Investment in international CO2 transport and storage infrastructure must start now in order to deploy CCS widely from 2025 – a delay of even 10 years will cost power and industry an extra €200 billion to reach EU climate targets. The right incentives have to be in place to make this happen.

The adopted Innovation and Modernisation Funds are vital for the development of CO2 transport and storage infrastructure. This can in turn realise CO2 hubs and low-carbon industrial zones, attracting inward investment and creating a significant number of jobs. We now need to ensure that 'part-chain' CCS projects are also eligible and that the funds interact flawlessly with other EU level funding instruments".

Pöyry Management Consulting report demonstrates business case for UK Industrial CCS

www.teessidecollective.co.uk

Against the background of an emerging UK industrial strategy and the forthcoming publication of the UK Government Emissions Reduction Plan, this new report by Pöyry Management Consulting sets out the business case for an Industrial CCS support mechanism in the UK.

The report proposes a business model that could make cost-effective, near-term investment in CCS attractive to both Government and to Energy Intensive Industries (EIIs) and so form a basis to enable the Government and industry to jointly take forward delivery of Industrial CCS.

The report was written in collaboration with the Teesside Collective, an industry coalition comprised of companies based in the Tees Valley region and funded by the Department for Business, Energy and Industrial Strategy.

Key report findings:

• Carbon Capture and Storage (CCS) is a technically proven technology for application to industrial emissions currently operating at sites worldwide, and the only viable option for deep emissions cuts for many UK industries.

• Building on Lord Oxburgh Parliamentary Advisory Group report recommendations for separation of CO2 capture from CO2 transport and storage (T&S), the report proposes a commercially feasible industrial CCS business model identified and tested through broad stakeholder input with both industry and Government.

• Using the identified business model as a basis, total lifetime cost for capture, transport and storage for a cluster of industrial CCS projects developed using shared T&S is below 60/tCO2 when using data from the Teesside Collective 2015 Blueprint study.

MIT extends collaboration with Eni

energy.mit.edu

The $20 million agreement includes an extension of Eni's founding membership in the MIT Energy Initiative (MITEI) and research support for three of MITEI's Low-Carbon Energy Centers to advance key technologies including CCS.

The Low-Carbon Energy Centers are a core element of MIT's Plan for Action on Climate Change, which calls for engagement with industry to address global climate challenges that demand society's urgent attention. Participation in the centers fits with Eni's commitment to an energy transition and addressing climate change.

As part of the continuation of the collaboration, Eni and the MIT Energy Initiative have recently begun research programs focused on carbon capture and utilization, energy storage, and uses for natural gas resources that would otherwise be wasted with flaring — with the goal of finding low-cost and industrially scalable technological solutions.

"Addressing climate change and pursuing breakthrough technology research are priorities for Eni. The collaboration with MIT and other European and Italian universities is of paramount importance," said Claudio Descalzi, Eni's CEO. "Eni is strongly committed to pursue a strategy of energy transition.

This is demonstrated by the challenging targets we have set for carbon dioxide reduction. Since 2008, we have already reduced our direct emissions by 28 percent and we aim by 2025 at a reduction per produced barrel of 43 percent compared with the levels in 2014.

MIT, the top academic institution worldwide for breakthrough innovation, is the ideal partner to address research in key technologies that can lead us toward an increasingly cleaner future."

"At MIT, we are determined to make a better world, and developing new low-carbon energy answers is an important step in that direction," said Reif.

"Our researchers have the ingenuity to invent new materials, technologies, processes, and policies. But for their work to reach the marketplace and make an impact on a global scale, we count on creative partnerships with visionary firms like Eni. We are inspired and grateful that Eni has chosen to sustain this productive collaboration."

The MIT-Eni collaboration has also included development of wearable technologies and systems to improve safety in the workplace, environmental research that has led to new soil assessment methods — which have already been applied in field tests — and advanced modeling of reservoir and petroleum systems.

Latest with carbon capture and utilisation

There are already business opportunities in carbon capture and utilisation (CCU) – including making plastics, building materials and fertiliser. We looked at the current state of affairs at our Nov 28 London conference.
By Karl Jeffery

Companies are already seeing real business opportunities using recycled CO2 to make plastics, building materials and fertiliser, we learned at our Nov 28 London conference "Update on Business Opportunities in CO2 Utilisation".

There is a mix of objectives – it can be about avoiding CO2 emissions, converting surplus renewable electricity into chemical storage, or providing chemical benefits to carbon capture and storage (CCS), or all three at once.

Although the mixed objectives add a great deal of complexity – for example if you are trying to convince a politician to take interest, you need to know which of these objectives they are most interested in.

Some people argue that by trying to make a case to politicians for CCS and CCU, with the different business case for each, you risk "pulling the sheet from many different corners," and it could be counterproductive.

Delegates at Carbon Capture Journal's conference in London focussed on opportunities for carbon capture and utilisation

But there is also a growing argument that people behind CCS and CCU would be much better off not fighting each other but working more closely together and developing a strong narrative for both, around CO2 being seen as a valuable product and CO2 is the industry of the future.

Starting point

Perhaps the best starting point to understanding the business case for CO2 utilisation is recognising that it can be used together with surplus renewable electricity to make liquid fuels, which can then be used in our current vehicle fuel infrastructure (but emitting CO2 again).

In order for our energy over a certain level to be renewable, we need to find a better way to store the energy, because the patterns of renewable energy generation to not match the patterns of energy consumption. Experts say that by 2030, everywhere in Europe will have electricity stability problems, unless there are good storage systems, according to our opening speaker Hans Bolscher.

CCU is not necessarily the best storage option – but it is a possibility, (alongside batteries, pumped storage, and others) and perhaps we will need to do all of these.

A second starting point is to say, we can't make plastic from fossil fuel sources forever. If we want plastic but don't have fossil fuel, we'll need the carbon for the plastic from another source.

Carbon is also a component in many industries and not just for process- heat but also as component in the final product. So – even if you make the process heat renewable - you would still need carbon, and if it didn't come from fossil fuels it would need to come from another source.

Perhaps the weakest argument, actually, is seeing CO2 utilisation as a way to save the climate. Actually if you push the climate issue too much, you can get strong counter reactions which can turn the whole discussion negative, said CCU consultant Hans Bolscher. It is better seen as one of many technologies that could be helpful for the climate, he said.

By comparison, carbon capture and storage (CCS) has just one and only one clear goal – the climate, he said.

In the political arenas, particularly in Germany and Brussels, CCU is steadily growing in support. "People really believe it and hope it will solve part of our problems," Mr Bolscher said.

Today, Covestro, a chemical giant, is providing a foam for mattresses using re-cycled CO2. Today it is also possible to build a house with bricks made from recycled CO2, made by Carbon8 Systems.

The technology could be interesting for people living on an island, if they can use power from a wind turbine to make fertiliser and vehicle fuel, and so become independent, rather than pay high costs of transporting oil and fertiliser.

The technology could also be used for aeroplanes, as a means for them to fly on liquid fuels but zero emission, provided the CO2 released when the fuel is burned is not originating from fossil fuel but from e.g. biomass combustion (so not adding CO2 to the atmosphere)

But unfortunately there is pretty much no direct business case at all, said Mr. Bolscher.

We are used to burning long molecules of hydrogen and carbon, so we end up with CO2 and water. Now we are considering the reverse – taking CO2 and water and making long molecules with it.

“Something you would normally break down, now you're going to build it up, costing lots of energy and money. It doesn't seem very logical,” he said but under certain conditions it can be the right choice, especially if you fix the CO2 more permanently like in mineralization.

Hans Bolscher

Mr Bolscher was formerly director for climate and industry in the Dutch government then director for CCS. As part of this role, he was responsible for the Barendrecht carbon capture project which was cancelled in 2010, which is “rather famous in the Netherlands as one of the failures of CCS,” he said.

“It was a very good project and very wise, everything was set to do it, the money was good. But people didn't like it, and that's an issue. Politicians get a bit wobbly, and it’s not going to happen,” he said.

After that he became a consultant, where he was given a task of evaluating the CCS directive for the European Commission, and helping the EC develop its thinking on the future of CCS. He also got involved in CCU at the same time.

More recently, he has been active in the SCOT “Smart CO2 Transformation” project, the first major European scientific project to research the possibilities of carbon capture and utilisation.

Mr Bolscher is currently involved in a project called “Carbon Next”, together with the University of Sheffield and German chemical association DECHEMAR, to try to map the various carbon monoxide and CO2 sources as future basis for CCU.

CCU consultant Hans Bolscher, formerly director for climate and industry in the Dutch government then director for CCS, opened the conference

CCS vs CCU

Right now, neither CCS nor CCU have got off the ground, and so it “would not be wise to say one is further than the other,” he said.

It isn’t even clear which one could potentially have a bigger market. CCS could be a huge industry, and so could CCU.

CCU also needs captured CO2 – and if the CCS industry is capturing big volumes of CO2, it can be made available for CCU.

Probably both CCS and CCU will work in the future with the same CO2 pipelines.

So we can say CCS and CCU are really different, but also related, he said. They don’t have the same reason for existing.

Mr Bolscher prefers the term “CO2 utilisation” to CCU, because CCU “reminds people in Brussels too much of CCS and that's not positive [in Brussels],” he said.

Three pathways

Mr Bolscher was involved in a EU funded study of CO2 utilisation options by the “SCOT” (Smart CO2 Transformation) project. The project emphasised that it was looking at CO2 transformation – converting CO2 into something else – rather than direct CO2 utilisation, for example in soft drinks, oil reservoirs and greenhouses.

The SCOT project research identified three routes for making value from CO2 – making chemical industry building blocks, synthetic fuels, and mineralisation. Sometimes the pathways to make chemical building blocks and synthetic fuels are the same, but the end use is different.

Mineralisation

One of the biggest surprises of the SCOT project was that mineralisation could be the most viable CO2 utilisation technology.

There are many fans of CO2 mineralisation, promoting the idea of taking CO2 out of the atmosphere by slowly reacting it with olivine (magnesium iron silicate), a common mineral in the earth’s subsurface.

This reaction can be speeded up with more heat, pressure, or by grinding it up smaller, but that all takes more energy, he said.

Olivine supporters proved to be a thorn in the discussions about trying to get carbon capture and storage going in the Netherlands around 2007, which Mr Bolscher was previously leading.

"They said, 'You don't need CCS because you've got olivine.' This became very awkward. I had to explain to a professor that his calculations were really wrong. At that time I was dead against it. I thought this is just an attempt away from CCS," Mr Bolscher said.

Now, about 10 years later, mineralisation is proving itself to be relatively simple compared to other processes, and relatively cheap (although not quite cheap enough), and with potential to work at high volumes. And the CO2 can be sequestered forever.

However it continues to be the least popular technology with politicians. "I don't know why this is, [maybe because] stones are a bit simple."

Liquid fuel

The second most viable option is making liquid vehicle fuel from captured CO2 and renewable energy, via electrolysing water to make hydrogen. These liquid fuels which can go straight into our current cars.

However the costs of this are huge, Mr Bolscher said. From the climate's perspective, it would probably be cheaper to use the renewable energy to do run vehicles directly on Hydrogen or renewable electricity.

Also, when running vehicles on these synthetic fuels, you will still emit CO2 when you drive the car. So in the end this is not good enough to solve the climate problem. Therefor he considers this NOT to be the right direction.

However this idea goes down very well for European politicians, who also like the idea that Europe can make its own liquid fuel.

But there are vehicle applications where batteries are not suitable, such as heavy lorries and aviation, which we will probably still want to use in a post fossil fuels era.

Turning CO2 into fuel may also make sense as a means of using surplus renewable energy.

There are "tempting elements" of the proposal. You can keep cars and vehicle pumping stations fairly close to how they are now, and build something quickly which can absorb surplus renewable energy, he said.

The technology of making synthetic liquid fuels is similar to the 'coal to liquid' technology used by South Africans during Apartheid and used by Germans in the Second World War.

Chemicals

A third viable option is using captured CO2 as a building block for making chemicals which we currently manufacture today.

There can be safety benefits for this, as well as finding a pathway to use CO2. Making polyurethane conventionally today is a very dangerous process, using phosgene, which is "not a nice gas to have in an industrial area". It can be made much more safely from CO2.

The SCOT project published a research action plan, showing all the different chemical building blocks, and where efforts should be concentrated.

There are many chemical reactions which can work at laboratory scale, but making them work in large chemical plants will take a long time.

The work making chemicals from CO2 is essentially doing the reverse of what chemical companies have been doing for decades, trying to make chemicals as effectively as possible from fossil fuels, with CO2 emitted as a waste product, he said. It is "really not easy, it is absolutely not cheap."

Government support

In terms of government support, CCU needs strong policies which make its products more attractive than the alternatives, since fossil fuel will be easier and cheaper. It probably also needs government funding for technology development.

CCU also needs realistic stories and good explanations for the public and politicians.

One of the most compelling stories is to simply say that this is the future. "We need to make stuff smarter than oil, that's what this is about," he said. "It is about industrial innovation, the next step of chemistry."

"It is an optimistic story, that supports a popular circularity [recycling CO2]. That's the tone of voice that would go down well with politicians."

Government support for CCU is unlikely to come via the Emission Trading Scheme, because the carbon price is too low and the overall CO2 savings often too unclear.

Support is more likely to come from government schemes for investing in innovation, for example perhaps pilot plants could be financed out of the European Union's NER 400 scheme. "It is one of the major subsidy lines from European Commission," he said.

By comparison, the sales message to politicians is relatively simple for CCS, to say, this is what we need, we don't have another solution. "Tell that time and time again. In the end they will understand and pay for it."

More information

Video presentations from the conference are online at:

www.carboncapturejournal.com

Tees Valley developing CCU plan

Tees Valley, one of the densest areas of energy intensive manufacturing in the UK, is looking for ways to develop carbon capture and utilisation industries. Low carbon manager Mark Lewis explained.

Tees Valley Combined Authority, an organisation which brings together five local authorities in Tees Valley, has commissioned Sheffield University, Pale Blue Dot Energy, Costain to work out what it could potentially do with carbon capture and utilisation (CCU).

Tees Valley is one of the most concentrated areas of energy intensive manufacturing in the UK, even despite recent steelwork closures, said Mark Lewis, low carbon manager with Tees Valley Combined Authority. There is plenty of CO2 around.

Overall, Teesside industries generate £2.5bn annually for the UK economy, but CO2 emission per person is three times higher than the UK average, he said.

When exploring the CCU business potential, Tees Valley focussed on chemical and biological routes and did not include CO2 storage, CO2 enhanced oil recovery, or use of CO2 directly in food (such as soft drinks).

The most practical technology turned out to be mineralisation. The CO2 could be used to make concrete blocks or be reacted to create a fertiliser (as CCm is doing) which avoids emissions from conventional production.

The chemicals route proved to be attractive because it fits with Teesside's established industry, he said. Opportunities include making platform chemicals including methanol, formaldehyde and polymers, such as polyurethane, and other intermediates. "They are close to market and potentially can achieve a premium in the market place," he said.

There are opportunities too making small volume speciality chemicals.

The volume of CO2 which could be used initially in chemical and biological routes is smaller than the amount which could be used in storage or EOR. "We understand that getting utilisation to a level [volume] where it's going to be effective [at reducing CO2 emissions] is going to be a long haul," he said.

The study also looked at how these processes might be put in place, and how a demonstration facility could be put together, showing how to make commercially viable products form CO2.

There are some complexities with linking CO2 capture with utilisation, including making sure the CO2 has the right purity, compressing it and transporting it, and being able to provide CO2 at low volumes.

Tees Valley wanted to identify technologies with a high "Technology Readiness Level", either in the market place or likely to enter it.

"There's an awfully wide range of TRLs, from 'gleams in people's eyes' to 'in the market place'", he said.

The vision is for industrial sites to be connected to a CO2 network, which would connect to offshore storage or CO2 utilisation opportunities.

Industry has taken many measures to reduce CO2 emissions over the last decade, and whilst progress is being made it gets harder and harder to do. Also some processes produce CO2 as part of the process itself, which cannot be avoided.

Mark Lewis, low carbon manager with Tees Valley Combined Authority

Through the Teesside Collective the region is now looking at how to put together a demonstration facility for using industrially based CO2 emissions.

The Combined Authority is also proposing the use of hydrogen for domestic heating (since there is no CO2 in the flue gas), as well as more use of surplus heat via district heating, reducing CO2 emissions elsewhere.

The companies in Tees Valley are looking hard at it and looking for commercial justifications, and there are other companies who might be interested in getting more involved. "I wouldn't say [they are] jumping on it, but certainly interested in it and prepared to look for ways forward," he said.

One company showing particular interest is Lotte Chemical, which makes plastic (PET) used to make soft drink bottles, and produces 55,000 tonnes of CO2 annually. They are interested in capturing and potentially using the CO2. This would improve the sustainability of its product, as well as become another revenue source.

More information

teesvalley-ca.gov.uk
www.teessidecollective.co.uk

Skytree – making CO2 air capture viable

Skytree of Amsterdam, a spin-off company from the European Space Agency, is moving ahead with its plans to make CO2 air capture viable – with the most likely first market now vertical urban farms

Skytree, a company based in Amsterdam, is making progress in commercialising its technology which captures CO2 from the atmosphere, originally developed for use onboard spacecraft (removing CO2 exhaled by astronauts), by the European Space Agency (ESA)

The company's most likely first market is now as a component for vertical urban farms, where plants a grown indoors in racks, in sealed spaces. The CO2 can be pumped in for use as a fertiliser. Having a CO2 rich environment can increase crop yields 30 to 40 per cent.

Skytree is working with an urban farming company in New York, looking to integrate its technology in a growing unit, planned to be on the market in 2017. It will pull about 30g CO2 a day from the air, and be integrated as part of a larger unit. The plants are grown in a sealed container, where the CO2 concentration is kept steady at 50 ppm, the ideal growing environment. This unit could cost "a few hundred euros".

The company is also developing the technology for use for home aquariums, whose owners like to bubble CO2 into the tanks to help aquarium plants to grow.

The company was initially funded by the ESA in 2010, as part of its mission to try to find societal benefits from research into space technology, said Max Beaumont, company founder.

The company has been supported by grants, including Climate KIC (a EU climate innovation innovative), as well as some angel investors, and now 3 venture capital companies.

The company has a team of about 8 people, most of which are developing prototypes for the technology.

The company wanted to make a 'platform' for making products which could be built at different sizes, not one-off devices.

The most commercially viable products are products which can be easily implemented in everyday life, and paid for without subsidy, he said.

In January 2017 it will have built a 'proof of concept' for its table top device which can pull 500g CO2 a day from air.

Other business applications include using the CO2 to support adding minerals to distilled water on ships and oil rigs to give it a more normal taste. The CO2 can also be added to swimming pool water to manage the acidity level.

The device can replace bottled CO2, which has been available since the 1970s for various different applications. It is supplied in heavy cylinders which are hard to use, not very safe and need to be replaced every few weeks, Mr Beaumont said.

The Skytree unit can provide CO2 continuously, and be used anywhere – including in the middle of an ocean or city.

Skytree is involved in a EUR 2.2m, EU backed project called Willpower, which will develop CO2 supply units for residential use.

It is also working with a German company called Gensoric, to develop a pilot plant which can produce 10kg methanol a day by 2018, using the captured CO2.

It has signed Heads of Agreement with a car manufacturer to develop a CO2 extraction unit for cars, taking CO2 out of cabin air.

It has been selected to join an EU funded project called "Roadmap Next Economy", to regenerate the economy of Rotterdam and Den Haag (Netherlands).

The volume of CO2 in each application is very small, but that doesn't mean that the overall market for the technology is small.

There are an estimated 50m (15m?) aquariums in the world, which could all benefit from better CO2.

Technology

The critical component of the unit is a 'sorbent' material which CO2 will adsorb onto, which was chosen through extensive research at the ESA on the basis of CO2 adsorption capacity, cost, volume and stability.

The sorbent is supplied as 0.5mm diameter plastic beads, and can capture 8 per cent of its weight in CO2. It costs Eur 8 to Eur 16 per litre, and two litres weigh 1kg. It can last 3-5 years.

Skytree produces a device containing a chamber containing the sorbent which can be vacuum sealed and heated.

The chamber is opened to the atmosphere and air flows in and CO2 adsorbs to the material. This takes around a week.

The chamber is then sealed and heated to 80 degrees C causing CO2 to desorb. It is then opened and exposed to the upstream end of a compressor, driving the CO2 out of the chamber into a pipeline.

Many people's initial reaction to the idea of direct air capture is that it could never work, because the concentration of CO2 in the atmosphere is so low, it would be better to concentrate on sources with a higher CO2 concentration, like coal power flue gases, Mr Beaumont said.

But the relationship between CO2 concentration and energy needed is not a straight line – it works out that you need about 2-3 times more energy to capture CO2 from air (0.04 per cent CO2) than capture it from a flue gas (20 per cent CO2).

“That motivates us to keep looking at this technology and bringing it further,” he said.

The company has not yet been able to reliably measure the energy consumption, so these are theoretical figures for now.

Air capture has advantages over flue gas carbon capture in that you only capture the CO2 you need and you can capture it where you need it. The units can be manufactured in bulk all exactly the same, whereas flue gas capture technology needs to be designed differently for every application.

And the air carbon capture user is not dependent on anyone else’s plant to get the CO2 they need.

Although of course CCS would be cheaper for larger scale applications, he said.

The company does not calculate the cost per kg CO2 – instead, it prices the unit on the basis of what people are paying now. For example, it could cost the same, for aquarium owners, as a system for working with bottled Co2, but without the ongoing cost of the CO2 bottles.

The energy consumption for a domestic unit could be around 60 Watts.

There are some technical complexities. The units are heavy, they have some high pressure elements. There are many complex components, including fans, pumps, heaters, the enclosure, control systems and casing, and cartridges for the sorbent.

Any cigarette smoke in the air supply degrades the sorbent very quickly. The sorbent beads can also be difficult to store, with their small size.

The company needs to develop ways to supply the sorbent in cartridges, so it is easier to replace them, and it will probably agree licensing deals rather than manufacture itself.

It is not an easy sell to investors, looking for an exit in 4-7 years, he said.

More information

www.skytree.eu

Carbon8 Systems – CO2 for building materials

Carbon8 Systems of the UK has been behind the conversion of CO2 into building materials for five years. Technical director Colin Hills explained how the business works

UK company Carbon8 Systems has developed a process (Accelerated Carbonation Technology - ACT) for creating construction materials (aggregates for use in e.g. concrete blocks, from captured CO2. The process has been commercially available for five years.

Colin Hills, technical director, explained how the business works.

The company accepts a gate fee for taking a waste – as any other waste management company would get paid, and at that point, it has liability for the waste, including during processing into manufactured carbonated product. The product has to meet a stringent 'end of waste' specification agreed with the Environment Agency, or it remains waste and must be treated as such.

In the UK, Carbon8 Aggregates (a separate company) offers ACT for treating air pollution control residues (APCr) and the company’s latest plant is in Avonmouth, UK. You can see silos full of wastes (the waste is enclosed). The plant is quite compact and the aggregate, which looks like limestone, can be tailor made as e.g. a 15mm graded product. Currently, the aggregate ends up in medium-dense concrete blocks. One customer, Lignacite, produce a construction block called 'Carbon Buster', and claim it is the "first carbon negative construction block in the world.”

The technology therefore has a Technology Readiness Level of 9, the highest level, defined as “Actual system proven through successful mission operations.” By ca. 2021 Carbon8 Aggregates plan to have 5 or 6 plants in the UK, producing half a million tons of aggregate a year.

Carbonated manufactured aggregates have been successfully tested for use in roads, in ready mixed concrete and pipe bedding. It is also possible to make higher value materials, for example with a controlled porosity for applications outside of the construction industry.

The technology should be extended to other wastes and eventually to other processes, he said.

Big picture

Looking at the big picture, the world needs to be able to reduce annual CO2 emissions by 8-12 Gt by 2030, in order to limit global warming. This is the emissions gap.

The global aggregates (coarse materials used in construction) industry is ca. 50 Gt a year. If 20 per cent by weight of this was recycled CO2 captured in manufactured aggregates, then the emissions gap could be closed.

Professor Hills has seen estimates that 95 per cent of all the construction materials made by mankind remain in the built environment, and this suggests that CO2 sequestered into building blocks or other products will remain as a solid, and not be released to the atmosphere in medium term. “For the last 10,000 years, we've been making construction materials, he said.

The wastes, such as those processed at Avonmouth can react with 20 per cent of their own weight of CO2, if they react completely. This means that every tonne of waste treated, 200kg of CO2 is mineralised as calcium carbonate (limestone).

In future there could be aggregates much richer in CO2, including those made from wastes not yet considered for treatment by a carbonation step.

Background

Carbon8 resulted from research conducted the late 1990s focused on, trying to find new ways to handle contaminated soils. When carbonating soil with gaseous CO2, it was observed that soil grains would develop a carbonate coating that was resilient to weathering. This was the first clue that a hard stone-like product might be possibly be fabricated to replace natural aggregates.

The company was invited to trial its technology on soil washing residues in London's Olympic Park. Carbon8 set up a 4m3 carbonation reactor, and the treated soil was fit for placing back into the ground as an engineering soil, in which the contaminants were stabilised.

Looking at a carbonated aggregate under a microscope, the shape and structure resembles a pisolith with layers of carbonate growing around each other, like tree rings. By changing, for example, the amount of moisture available and the residence time during processing, you can change aggregate grain shape, size and grading to suit.

Making it work

There are lots of hoops to jump through before the process could become commercially available.

First, the authorities have to agree that you can accept and treat waste. This means demonstrating your process is effective, and the products meet defined standards as demonstrated by independent/third-party testing. Thus, in order to sell the product, you need to prove that the aggregate product is fit for purpose as a suitable as a replacement for stone. Otherwise it can't be sold and will end up being managed under waste regulations, i.e. disposed of in a landfill.

Carbon8 has managed to get its regulatory acceptance for the process in the UK, and its licensee Carbon8 Aggregates has been selling the aggregates made from APCr for 5 years.

Unfortunately, within Europe, waste regulations are not consistently applied – so a process which works in the UK does not automatically receive approvals in other parts of the European Union, he said.

If Carbon8 is bringing new materials into the building supply chain, there should be a way of changing the material supply chain standards to accommodate it, he said.

It can be a challenge persuading customers to use novel materials. For example, one potential customer said that they would not touch a product unless it had been in use for 15 years. This attitude creates a significant hurdle to getting new materials in the market.

Colin Hills, technical director, Carbon8

Carbon8 would benefit from an educational campaign, so more people are aware that useful materials can be made from carbon dioxide, and there are wide benefits that include meeting the needs of the circular economy.

"I also think that, particularly in the short term, if you can get some value from using CO2 to make a product you should be able to claim that from some sort of taxation mechanism."

"I think an embodied carbon marking scheme for most products would be useful, to help customers make a choice and improve corporate responsibility."

Acquiring CO2

The technology does not need a pure CO2 stream – but you cannot easily extract CO2 rich flue gas from a power station.

"All the CO2 that is currently used is food grade and comes in a nice shiny tanker. The high cost of CO2 is critical going forward, and it is very difficult to get a point source of CO2 to where you want to locate your plant."

If lower cost CO2 was available, it would also make it possible to broaden the market, applying the technology to less hazardous wastes (where the payments for keeping them out of landfill are lower).

The Avonmouth plant is half a mile from a waste incinerator, but the company can't access the CO2 from it. "The operator certainly wouldn't allow anyone to drill a hole in the side and connect a pipe," he said.

Transporting aggregates is expensive, so it makes sense for Carbon8 to build its plants closest to its customers.

More information

www.c8s.co.uk

Katy Armstrong – CO2 utilisation story is complex

A challenge with CO2 utilisation is that it is working towards many different objectives – which makes it hard to get political support behind it, said Katy Armstrong of the University of Sheffield

CO2 utilisation can be about avoiding CO2 emissions, converting renewable energy into chemical storage, providing economic benefits to CCS, and all three at once.

But that gives us a bit of a problem when we go and speak to people about what CO2 utilisation is, said Katy Armstrong, CO2Chem Network Manager at the Department of Chemical and Biological Engineering at the University of Sheffield.

"Everybody has a different background and motivation for why they want to do it," she said. It is important to bear that in mind when talking to people about it.

People are entering different markets and making different products.

CO2 can be turned into many different products, including fuels, polymers, intermediates, inorganic and organic carbonates, carboxylates and lactones, even biomass (growing something in the CO2).

"This is what makes CO2 utilisation complex to explain to governments and people who want to invest."

"It is very easy to talk about one aspect of CO2 utilisation and the product you're making. But if you want to explain the whole remit it gets very complex very quickly."

CO2Chem

CO2Chem is a network of people interested in CO2 utilisation which anybody can join, funded in the UK by the Engineering and Physical Sciences Research Council (EPSRC). It exists to help people working in the field to connect each other.

As well as running CO2Chem, Ms Armstrong works as a researcher for the UK Centre for CO2 Utilisation ("CDUUK"), based at the University of Sheffield.

CDUUK has been working on the European Union funded "SCOT" project, and will next work on an EU funded project called "CarbonNext", looking at new sources of carbon for the process industry.

Current businesses

Ms Armstrong gave an overview of some of the businesses currently in operation in CO2 utilisation.

Covestro (Germany) is making memory foam polyurethane mattresses from recycled CO2, which will be available "in the next couple of years", and perhaps a personal buyer would be willing to pay a little more for a greener product...

Carbon Recycling International (Iceland) is making methanol from CO2, using geothermal power, and CO2 from flue gas from a power plant. This methanol can be used as a vehicle fuel. "They say they have a business case to take that product and that process around the world," she said.

Novomer Inc (USA) is a plastics company making coatings and adhesives from re-used CO2, some of which are used in products sold by Kingspan, a building materials supplier.

LanzaTech (USA) is making biofuels with algae.

Skyonic Corporation (Texas) is mineralising CO2 to make bicarbonate products such as bicarbonate of soda.

Sunfire (Germany) is making synthetic fuels for cars, in a tie-up with Audi. "It is not economic at the moment. But they do have a demonstrator plant making up to one barrel of diesel a day. I have seen it put in a car and the car driven away."

Recoval (Belgium) is a mineralisation company, taking waste slag from the steel industry and turning it into building material.

Also CCm Research (UK company making fertilisers) and Carbon8 (UK company making building materials), who presented their companies in more depth at the conference.

"There are some really good stories out there. New products and new companies appearing on the scene all the time. "A lot of these are small enterprises or spin-outs from universities, sometimes you don't hear about them until they are quite far down the track."

How much CO2?

There are various data estimates about how much CO2 could potentially be utilised.

One of the most respected academics in the field is Michele Aresta, Full Professor of Inorganic Chemistry at the University of Bari, Italy. He calculated in 2013 that by 2016 we would probably be utilising 300 megatonnes of CO2 per year, which is "probably about right," Ms Armstrong said.

Another researcher, Gabrielle Centi, professor of Industrial Chemistry at the University of Messina, Italy, calculated that by 2030 the world could use up to 1.5 Gt CO2 / year.

The Global CO2 Initiative, based in San Francisco, has just produced a report saying we could be using 7 Gt CO2/ year by 2030. "The research was done by McKinsey, but as with most of the calculations for CO2 use, you can't access the data behind it; I'd really love to see it," she said.

Some of this "used" CO2 will end up being emitted further down the line (for example if it is used to make a synthetic vehicle fuel) and you need to account for the energy inputs. "So there's a lot more to the story than these headline figures."

Ms Armstrong and Prof Peter Styring, director of CDDUK at the University of

Sheffield, have also conducted similar research looking at CO_2 utilisation potential and also ended up with a figure of 1.5 Gt CO_2 by 2030.

This research looked at CO_2 being used to make chemicals, in waste mineralisation, making polymers, making diesel and aviation fuel, and making methane.

In terms of the source of CO_2 recent research from Germany has highlighted that sources like ammonia production and hydrogen production, and fermentation of biomass should be targeted first due to their higher concentrations of $CO_2$and more beneficial environmental impacts.

But the point is, there are sources of CO_2, and different environmental arguments for all of them, she said.

Fitting with policy

The SCOT project did some research about how CO_2 utilisation should fit with the Emissions Trading Scheme (ETS).

"We recommended that mineralisation technologies fit into ETS very clearly because we can guarantee CO_2 is locked up and stored for a long period of time," she said. But "when you start talking about making chemicals - polymers, fuels - it gets far more complex."

Trying to amend the ETS policy to find a way to incorporate CO_2 utilisation to make chemicals may be more effort than it is worth, she said. There would need to be a lifecycle analysis showing how long CO_2 is stored for.

There are also discussions about whether fuels from recycled CO_2 could be treated as comparable to biofuels.

You would need to be able to prove any energy used to make the fuels had come from renewable sources.

The methanol community would like a larger amount of vehicle fuel to be methanol, which could then allow a methanol from CO_2 utilisation market to grow.

There are also complex discussions about how CO_2 utilisation fits in with the Waste Framework Directive.

For any CO_2 utilisation project, it is useful to do a detailed lifecycle analysis, to provide detailed answers of how much CO_2 is being avoided or stored. Both CCm Research and Carbon8 Systems (who presented at the conference) do this, she said. "We need far more people doing life cycle analysis right now."

"Our lifecycle analysis needs to have the broadest boundaries we can possibly have, to make sure what we are giving is a clear representation of the environmental impacts of the whole process.

Overall not all technologies have the same impact on the climate, and if there are different pathways to make the same product, one will probably have a better impact than others.

Market factors

There are many market factors affecting CO_2 utilisation.

There is some 'push' from companies which want to find better ways to dispose of something, like Virador, a waste recycling company, she said.

On the 'buy' side, the public does not seem that willing to spend more money for products which reduce CO_2 emissions – as an example, consider how few people are willing to buy CO_2 offsets for plane tickets, even when travelling to environmental conferences, she said.

Geographical factors vary – a CO_2 utilisation project might be more viable in one place than another. For example, it could be viable if you are close to a supply of a necessary waste product or feedstock.

Ms Armstrong has been involved in developing a tablet app called "CO2Go" which shows how products can be made from CO_2. The app aims to help people to understand the potential of CO_2 utilisation and understand the choices that can be made regarding energy sources, CO_2 and H_2 sources and the subsequent impact on CO_2 emissions and quantities of renewable energy required.

This is the first such app showing CO_2 utilisation routes. We are hoping to develop it further as it could be more sophisticated especially if there was data available about the costs of making different products, what they could be sold for and how the costs change in different countries or with different sources of energy. These data should become available as more techno economic analyses of CO_2 utilisation are published.

Publishing data

It would be helpful if there was more transparency in calculations in the industry, so it was possible to have discussions about how the calculations are made, and challenge them in some cases.

Choosing the right solutions needs a mixture of environmental and economic analysis.

Typically, companies don't publish life cycle analysis together with the underlying data. Often there is commercially sensitive information involved. But perhaps it could be done as part of university research work, based on hypothetical data.

Public and policy

It would also be helpful to have a deeper perception of public perception of CO_2 utilisation.

Many members of the public don't see the difference between using CO_2 as a chemical feedstock and with CO_2 gas. So (for example, they can worry that if they were to sleep on a mattress made from CO_2, the CO_2 could be released, which they would breathe and die. This is wrong as the CO_2 chemically transformed into the polymer.

CO_2 itself is not well understood by the public. In discussions with schoolchildren at GCSE level (age 14-16) studying chemistry, the researchers were shocked to find that some children through CO_2 could be used for children's balloons, like helium.

However, CCU has stimulated interest with UK politicians. CO2Chem produced a white paper called "Carbon capture and utilisation in the green economy" in 2011. The paper was sent to most Westminster (London) politicians and it had an "incredible" impact, she said, "resulting in political support and new funding opportunities and collaborations, not only in the UK but worldwide."

More information

www.sheffield.ac.uk
www.ukccsrc.ac.uk

A CCU / CCS battle?

Do CO2 utilisation and CCS compete or complement each other – or how should the people involved in each both best work together? Belinda Perriman and Hans Bolscher led a discussion panel

"Over the last year I am beginning to hear this language of battle between CCS and CCU," Belinda Perriman, CCS Commercialisation Manager with Tees Valley Combined Authority.

There is a really good symbiosis between CCS and CCU, she said. It is a like orchids growing on the top of trees in a forest and living together – the orchid doesn't kill the tree and the tree doesn't kill the orchid.

"Can we tell one story, covering direct air capture, CCU, CCS, build a narrative where we're supporting each other?" she asked. "We need to be telling a story over and over again."

Ms Perriman experienced frustration with battle narratives in her previous role as lead for Shell's Peterhead CCS project, where Shell tried to see itself as part of the solution to CO2 emissions. But the environmental organisations were used to seeing energy in a battle narrative between fossil fuel companies and renewables, and were hard to persuade, she said.

"Although energy production has been responsible for quite some significant amount of CO2 emissions, and burning it is a greater proportion of CO2 emissions, we had skills and resources to throw at it to be part of the solution. We can all work together on this."

At the COP22 conference in Marrakesh in November 2016, there were people saying openly that carbon capture and storage doesn't work, and the past Prime Minister of the UK (David Cameron) had said so.

"It's not the sort of language we ought to be using," she said. "David Cameron was using it in a different context, he was using it in a time after a difficult spending review."

CO2 utilisation is very complex, in terms of the various pathways, the chemistry options and the overall lifecycle analysis. But stories can be used to explain complex ideas to people, she said.

Belinda Perriman, CCS Commercialisation Manager with Tees Valley Combined Authority and Hans Bolscher, CCU consultant and former CCS director for the Dutch Government

The CCU and CCS groups should "see each other as part of the solution to reduce carbon emissions," she said.

"The real energy is us poisoning ourselves, not saying poisonous words about each other," she said.

Hans Bolscher

Hans Bolscher broadly agreed. "Yes there is no battle [between CCS and CCU] and there should be no battle, it is stupid and a waste of time we both want to do something good," he said.

"I think the origin [of the battle] is the struggle for funding, [people saying] 'you get more than I get' or it is popularity – 'you're popular, I'm not.'"

If there was CCS, the utilisation people would be happy, because there would be a source for CO2, and the CCS people would be happy that CO2 is no longer seen as a poison but something positive, he said.

The term "carbon capture and utilization and Storage" (CCUS) originated in a discussion when Maria Verhoeven, Dutch Minister of Economic Affairs from 2007 to 2010, who went on to be executive director of the International Energy Agency from 2011 to 2015, Mr Bolscher revealed.

She wanted to give a more positive twist to the CCS story, more than just 'storage', putting waste in the ground, end of pipe, as in CCS.

So instead she preferred to speak about Carbon Capture and Utilisation and Storage (CCUS).

However, Mr Bolscher stressed that CCU and CCS are not the same thing. There are stories around both of them, these stories are connected, but they are not the same stories, and perhaps should not be connected too much.

One area both CCU and CCS people should perhaps collaborate is in persuading people that there can be a business in CO2.

During the discussions about CO2 storage in the Dutch town of Barendrecht (2007 to 2010), the anti-CCS campaigners used the slogan “CO2 NO”.

“I said, ‘how do you want to live,’” Mr Bolscher said. “CO2 is getting a bad name. Utilisation gives it back its good name.”

Carbon policy

One audience delegate asked whether a strong carbon price could shake out all the complexity because there would be a market driven system to ensure the best methods work.

Belinda Perriman replied that some of the biggest oil and gas companies, including Saudi Aramco, have called for a high carbon price, and Shell has been calling for a carbon price for over a decade, seeing that as a pathway to making life simpler, and then industry could discuss the subtlety beneath it.

Hans Bolscher agreed that a carbon pricing is the best way to get CCS going. However it is not so beneficial for CCU, because the CO2 is not always ultimately stored. It moves to a more complex discussion about carbon avoided. And Life cycle analysis studies are “highly uncertain still,” he said.

If the main concern was getting rid of CO2, then CCS would be the way to go. CCU has other benefits, including for intermittent storage, and driving a range of new products.

One audience delegate suggested legislation requiring fossil fuel companies to store carbon as a condition for extracting more, perhaps on a slowly growing scale. This could be a more powerful driver than a tax or carbon price.

Ms Perriman replied that “a number of these schemes have been around.

“There must be some reason why we haven't moved ahead on them. I would see it as something that makes sense if we're serious about tackling climate change.”

“A lot of taxes can be passed on to the next consumer down the line. Legislation is often a better way to crack the nut.”

Mr Bolscher said that one useful lesson from his work evaluating the EU CCS directive is that ultimately it does not make much difference which regulatory vehicle is used, whether tax, emissions limit or restrictions on fossil fuel production. With each, it comes down to a judgement by a public authority about how tight the instrument could be, and this political judgement is the critical factor.

Legislation has proven extremely effective. But “the reason why we are so afraid of using legislation is the competition” [making EU products maybe more expensive compared to others),” he said.

This problem would disappear if the carbon price was applied globally, but “it’s not going to happen, not in the next 50 years,” he said.

There has been legislation proposed for coal power stations where they would have a maximum allowed emission, which automatically means they have to use CCS in order to operate.

“For oil companies doing something similar is possible, I don't know if you can do it at a global scale, and these companies are global, they think globally.”

One audience member asked about whether CCU can be packaged to the US administration to make it look more business focused rather than environmentally focused, bearing in mind Donald Trump’s climate scepticism.

Ms Perriman replied that both CCS and CCU can help keep coal mining jobs, steel jobs and chemical industry jobs, which were platforms he campaigned on. It can all lead to more valuable products and more jobs. And if a climate sceptic government was doing something serious about CCS and CCU that would be a big push to other governments around the world.

Also the biggest uses of CO2 are in enhanced oil recovery, which is a purely business project, not for climate, although the CO2 ends up being stored, she said.

More information

Video presentations from the conference are online at:

www.carboncapturejournal.com

Capture and utilisation news

A step closer to bringing CO2 membrane technology to markets

www.airproducts.co.uk

Air Products signs exclusive license agreement with Norwegian University of Science and Technology for membrane technology for CO2 capture technology.

The Norwegian University of Science and Technology (NTNU), through its commercialization arm NTNU Technology Transfer, announced that it has entered into an exclusive license agreement with Air Products. The agreement allows Air Products the rights to use NTNU's proprietary fixed site carrier (FSC) membrane technology in conjunction with Air Products' proprietary PRISM® membrane technology for carbon dioxide (CO2) capture applications.

The FSC membrane allows for a highly energy-efficient way of capturing CO2 from flue gas and biogas to produce a high-quality CO2 offgas. Air Products and NTNU foresee great potential for the application of this technology in areas such as coal-fired power plants and the cement industry, as well as other combustion processes.

"The combination of Air Products' PRISM membranes and NTNU's fixed-carrier technology moves carbon dioxide capture to a new level of efficiency that makes economic sense," said Charles Page, director of Air Products' PRISM Membranes division."

"Air Products is committed to developing solutions that enable our customers to minimize the impact of their operations on the environment. We are confident that our license agreement with NTNU will provide Air Products the technology to manufacture gas membrane separators that are revolutionary in CO2 capture."

Page also commented that the new agreement may open a new field of opportunity for the Norwegian affiliate of Air Products in Kristiansand.

This special membrane technology has been developed over the years at the Department of Chemical Engineering, NTNU, by Professor May-Britt Hägg and her research group and supported by Gassnova, the Research Council of Norway (CLIMIT and FORNY2020) and the European Union. Air Products (Norway and U.S.), Statoil, Norcem, Alberta Innovates, DNV-KEMA and SINTEF have also been important collaborators.

University of Texas develops new air capture method

www.ornl.gov

Charles Seipp, a graduate student in chemistry at The University of Texas at Austin, has helped discover a new method for capturing CO2 from the air and releasing it into long term storage.

Scientists at the Department of Energy's Oak Ridge National Laboratory have found a simple, reliable process to capture carbon dioxide directly from ambient air, offering a new option for carbon capture and storage strategies to combat global warming.

Initially, the ORNL team was studying methods to remove environmental contaminants such as sulfate, chromate or phosphate from water. To remove those negatively charged ions, the researchers synthesized a simple compound known as guanidine designed to bind strongly to the contaminants and form insoluble crystals that are easily separated from water.

In the process, they discovered a method to capture and release carbon dioxide that requires minimal energy and chemical input. Their results are published in the journal Angewandte Chemie International Edition.

"When we left an aqueous solution of the guanidine open to air, beautiful prism-like crystals started to form," ORNL's Radu Custelcean said.

"After analyzing their structure by X-ray diffraction, we were surprised to find the crystals contained carbonate, which forms when carbon dioxide from air reacts with water."

Decades of research has led to the development of carbon capture and long-term storage strategies to lessen the output or remove power plants' emissions of carbon dioxide, a heat-trapping greenhouse gas contributing to a global rise in temperatures.

Carbon capture and storage strategies comprise an integrated system of technologies that collects carbon dioxide from the point of release or directly from the air, then transports and stores it at designated locations.

A less traditional method that absorbs carbon dioxide already present in the atmosphere, called direct air capture, is the focus of ORNL's research described in this paper, although it could also be used at the point where carbon dioxide is emitted.

Once carbon dioxide is captured, it needs to be released from the compound so the gas can be transported, usually through a pipeline, and injected deep underground for storage.

Traditional direct air capture materials must be heated up to 900 degrees Celsius to release the gas -- a process that often emits more carbon dioxide than initially removed. The ORNL-developed guanidine material offers a less energy-intensive alternative.

"Through our process, we were able to release the bound carbon dioxide by heating the crystals at 80-120 degrees Celsius, which is relatively mild when compared with current methods," Custelcean said. After heating, the crystals reverted to the original guanidine material. The recovered compound was recycled through three consecutive carbon capture and release cycles.

While the direct air capture method is gaining traction, according to Custelcean, the process needs to be further developed and aggressively implemented to be effective in combatting global warming. Also, they need to gain a better understanding of the guanidine material and how it could benefit existing and future carbon capture and storage applications.

The research team is now studying the material's crystalline structure and properties with the unique neutron scattering capabilities at ORNL's Spallation Neutron Source (SNS), a DOE Office of Science User Facility. By analyzing carbonate binding in the crystals, they hope to better understand the molecular mechanism of carbon dioxide capture and release and help design the next generation of sorbents.

The scientists also plan to evaluate the use of solar energy as a sustainable heat source to release the bound carbon dioxide from the crystals.