Carbon Capture Journal

CCS in 2017

Global CCS Institute Status report: Paris climate targets cannot be met without CCS

An implementation plan for CCS in Europe

Jan / Feb 2018 Issue 61

Review of 2017 - Petra Nova was one of the highlights

- Evaluation of the NET Power low carbon power process
- 7th Carbon Sequestration Leadership Forum Ministerial Meeting
- Artificial photosynthesis gets big boost from new catalyst
- Exa and BP – get relative permeability from a digital rock sample

UK government now "back at the table" on carbon capture

The UK government is now "back at the table" to discuss carbon capture, after a difficult couple of years, said Luke Warren, chief executive of the Carbon Capture and Storage Association (CCSA), at an Oil and Gas UK breakfast meeting, "Strategies for oil and gas as part of a low carbon future."
By Karl Jeffery

The range of opinions about climate change within the British government are starting to narrow, with everybody being broadly in favour of action, just a divergence of views on how it should be tackled, Mr Warren observes. Donald Trump's election could have been an opportunity for an anti-climate change act lobby in the UK, or parliament, to gain a footing, but that never happened.

Mr Warren is encouraged by the fact that Nick Timothy, former joint chief of task to Theresa May, and not known for being a fan of climate change action, has been writing articles about the way that climate change should be driven, not whether it should be driven at all.

Mr Warren does not see carbon prices rising to the point that they can make carbon capture investment make sense, until "2030 at the earliest". Carbon prices are starting low and should gradually get high, but the cost of carbon capture is currently high but (as projects get built) should fall, as it did for wind and solar investment. That's a problem for funding carbon capture with carbon prices. So we do need other government policy to make carbon capture work.

Another interesting change is that the UK government's climate team now sit as part of the Department for Business, Energy and Industrial Strategy (BEIS). It was previously sat in its own Department of Energy and Climate Change (DECC). This may indicate a stronger commercial focus to the UK's climate discussions.

Mr Warren is also encouraged by the October 2017 announcement from the Oil and Gas Climate Initiative (OGCI), saying that it plans to invest in a project to design a full scale gas power plant to try to develop a commercially viable concept which can receive government support and investment. He sees this as news that OGCI plans to drive its own carbon capture project.

There are also interesting UK projects to develop hydrogen from gas, sequester the gas and provide hydrogen to cities, for both industrial energy supplies and to put as part of the gas grid - in Liverpool, Manchester and Leeds, Mr Warren notes.

Also at the event, Mike Tholen, upstream policy director for Oil and Gas UK, said that members are "starting to think a lot more about the future of the industry, and will there be a role for us".

Graham Bennett of DNV GL, presented his organisation's work to try to define what the worldwide 'energy transition' to renewables will look like, predicting that oil use will peak in the next 10 years, and gas use will peak in 20 years - although gas will remain the biggest source of energy for the world until 2050, and fossil fuels will still supply half the world's energy by 2050 – and the maximum temperature rise due to climate change will be 2.5 degrees.

Some thoughts from me. Considering that the oil and gas industry and carbon capture industry have a common skillset and use common reservoirs and topsides infrastructure, it seems likely that the oil and gas industry will be doing carbon capture, when it eventually happens. Perhaps the question is what financial structure will drive the industry to do carbon capture, not how the industry should respond to whatever financial structure there is.

And also - gas has the potential to be a zero emission fuel for transport and heating, if it is reformed to hydrogen and the hydrogen sequestered. That means we can carry on using gas in a zero emission era.

Also – It is easy to imagine that everything will become integrated - exploration and production, decommissioning, carbon capture and storage, perhaps offshore reforming, all happening at the same time. The industry will need to develop interesting new ways to work with digital technology to make all of that happen.

More information

See the powerpoints online:

oilandgasuk.co.uk

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Carbon Capture Journal
United House, North Road, London N7 9DP
www.carboncapturejournal.com
Tel +44 (0)208 150 5295

Editor
Keith Forward
editor@carboncapturejournal.com

Publisher
Future Energy Publishing
Karl Jeffery
jeffery@d-e-j.com

Subscriptions
subs@carboncapturejournal.com

Advertising & Sponsorship
David Jeffries
Tel +44 (0)208 150 5293
djeffries@onlymedia.co.uk

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Front cover:

The Petra Nova post-combustion carbon capture facility at NRG's WA Parish plant began operation and captured over 1 million tonnes of CO2 during 2017. The image shows a bird's-eye view of carbon capture facility with the taller Absorber Tower in the foreground and the Regenerator Tower next to it and the co-generation system at the top right

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Carbon Capture Journal Review of 2017

In 2017 China took the lead with plans for at least eight large-scale CCS projects. In Europe oil giants Total, Shell and Statoil joined to develop shared storage infrastructure, while in North America several projects reached capture & storage milestones and Alberta opened a new research station. The UK restarted its ambitions with a Clean Growth Strategy.

January

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

Oak Ridge scientists use a compound known as guanidine to capture carbon dioxide from ambient air and isolate the greenhouse gas using less energy than traditional methods

The UK Department for Business, Energy & Industrial Strategy did not achieved value for money for its £100 million spend on the second CCS competition according to the National Audit Office

ENI extends its collaboration with MIT in the MIT Energy Initiative (MITEI) and research support for three of MITEI's Low-Carbon Energy Centers

February

Oslo's main trash incinerator shows promising results in the world's first experiment to capture greenhouse gases from the fumes of burning rubbish

Australia's chief scientist backs taxpayer subsidies for CCS technology

BHP Billiton, the world's largest mining company, urges governments to provide more support to the industry for developing CCS projects

March

Yanchang Petroleum’s large-scale CCUS facility enters construction in China

CarbonCure receives up to $3 million from Emissions Reduction Alberta (ERA) to further optimize and accelerate adoption of its CO2 utilisation technology in Alberta

The U.S. Energy Department's Office of Fossil Energy selects seven projects to receive $5.9 million to focus on novel ways to use carbon dioxide captured from coal-fired power plants

An independent report commissioned by government, industry and research organisations has laid down a comprehensive plan for CCS deployment in Australia

The UK Public Accounts Committee launches an inquiry into Carbon Capture and Storage

April

Carbon Clean Solutions joins Veolia to offer large-scale de-carbonisation of a number of industrial processes under an Open Innovation approach

Shaanxi Yanchang Petroleum develops two carbon capture and storage projects which will use the captured carbon dioxide for enhanced oil recovery (EOR).

The Illinois Industrial Carbon Capture and Storage project, a partnership to safely and permanently store more than 1 million tons of carbon dioxide a year, begins operations

Gassnova, Statoil, Shell and Total announce that they want to participate in the continuation of the test operations at Technology Center Mongstad until 2020

The UK Carbon Capture and Storage Research Centre is awarded £6.1M by the Engineering and Physical Sciences Research Council to continue its work for the next five years

Research institutes across Europe join forces through a new scientific project named ENOS (ENabling ONshore CO2 storage in Europe)

Norcem, Yara and the Klemetsrud facility are all awarded financial support from Gassnova to continue their studies on carbon capture

A report published by the University of Sheffield outlines how the re-use of carbon dioxide could help Scotland shift to a more sustainable and circular economy

May

The UK Carbon Capture and Storage Research Centre and CO2CRC Limited sign a Memorandum of Understanding for continued collaboration

Gassco is commissioned by the Norwegian Ministry of Petroleum and Energy to clarify the basis for ship transport of CO2 from capture sites to the storage point

The UK Public Accounts Committee report warns that halting CCS deployment means taxpayers will have to pay billions more to meet targets

Aker Solutions will conduct concept studies for carbon capture at Yara's ammonia plant on Herøya and Norcem's cement production facility in Brevik, Norway

Anglo American's diamond unit De Beers is piloting a project to capture carbon in the rock from which diamonds are extracted to offset harmful emissions

The Acorn project, a full chain small scale carbon capture and storage project in Scotland receives support from the EU

The controlled production of brine from saline aquifers beneath the North Sea can greatly increase the amount of CO2 that can be injected for storage according to research

China's top steelmaking companies hold talks with Australian experts in Beijing on the introduction of carbon capture and storage technology

June

An IEA Clean Coal Centre report finds that awareness of CCS among the general public is low, and better-informed groups support other low-carbon technologies more than they do CCS

Carbon capture and storage is made eligible for funding in Australia through the Clean Energy Finance Corporation (CEFC)

The U.S. Department of Energy's Office of Fossil Energy (FE) invests $12 million to advance new geological carbon storage projects that enable safe, cost-effective, and permanent geologic storage of carbon dioxide

TCM signs a four-party Memorandum of Understanding to further progress carbon capture collaboration between Norwegian and Chinese Companies

An Energy Technologies Institute report confirms that large scale storage sites using shared infrastructure and existing low risk technologies would provide the lowest cost route to developing carbon capture and storage (CCS) in the UK

China definitely takes the lead globally in its effort to mitigate the effects of climate change beginning construction of the first of eight large-scale carbon capture and storage projects

A new test campaign named MEA-3 starts at TCM containing a number of sub-projects focusing on CO2 capture, emissions to air and model predictive controlled operations

A 'fingerprint' test developed by Scottish scientists to check for leaks from carbon capture and storage sites is used for the first time in Canada

The Cement Sustainability Initiative publishes a technology review on current and anticipated developments that can be used to mitigate CO2 emissions in cement production

July

Southern Company and Mississippi Power suspend start-up and operations activities involving the lignite gasification portion of the Kemper County energy facility

Gassnova assigns Statoil to evaluate the development of carbon storage on the Norwegian continental shelf (NCS)

Air photograph of Reykjavik Energy's Hellisheidi geothermal power plant. Swiss cleantech company Climeworks has partnered with Reykjavik Energy to combine direct air capture (DAC) technology for the first time with permanent geological storage. Credit: Árni Sæberg

Vattenfall with steel manufacturer SSAB and mining company LKAB forms a joint venture to develop a steelmaking process that emits water instead of carbon dioxide

European power giants Engie and Uniper withdraw from a test project to capture and store carbon dioxide generated by one of several major new coal plants in the Netherlands

Statoil, Vattenfall and Gasunie to evaluate the possibilities of converting Vattenfall's gas power plant Magnum in the Netherlands into a hydrogen+CCS plant

U.S. Senators Heitkamp, Capito, Whitehouse, Barrasso, Kaine and Graham seek to accelerate the use of CCS technologies by introducing a bill that expands a tax incentive

Scientists at Berkeley Lab develop a light-activated material that can chemically convert carbon dioxide into carbon monoxide without generating unwanted byproducts

August

The University of Twente and Jülich Research Centre collaboratie on membranes for the efficient separation of gases with potential applications in carbon capture and utilization projects

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) invests $4.8 million to investigate novel uses of carbon dioxide captured from coal-fired power plants

Kyoto University's Institute for Integrated Cell-Material Sciences, London's Imperial College and City University of Hong Kong creat a new 'mixed matrix membrane' filter

September

A Princeton University study shows CO2 storage would not be prone to significant leakage or high costs related to fixing leaks

Econic Technologies develops tunable catalyst that converts CO2 into polyols, a key building block in polyurethane plastics

Indian Oil Corporation Limited and LanzaTech sign a Statement of Intent to construct the world's first refinery off gas-to-bioethanol production facility in India

Canadian Province Ontario creates $25.8M fund to support green technologies

A Canadian Low Carbon Innovation Fund will support technologies in areas including carbon capture and usage

Canada invests $950k in state-of-the-art equipment for the Carbon Capture and Conversion Institute to develop and scale up capture and conversion technologies

CO2 Solutions to conduct a preliminary study to assess the viability of applying its enzymatic carbon capture technology in a potential 32-tonne per day CO2 capture project in the mining and metals industry

TU Delft PhD student Ming Ma finds a way to effectively and precisely control the process of electroreduction of CO2 to produce a wide range of useful products

U.S. Secretary of Energy Rick Perry announces $36 million in financial assistance to advance carbon capture technologies

The method developed at Edinburgh University that inexpensively monitors the safe storage of CO2 is to be used by a leading research project in Canada

The Carbon Capture and Storage facility at Boundary Dam Power Station resumed commercial operations following a shutdown that lasted more than three months

October

Econic Technologies partners with SCG Chemicals to develop processes to manufacture novel CO2-based high molecular weight polymers

Researchers from the University of Houston begin a $1.4 million project to demonstrate using carbon dioxide captured from nearby petrochemical plants to boost oil recovery in a field in the Indian state of Assam

U.S. Energy Secretary Rick Perry asks an oil industry advisory council to help find ways for oil drillers to exploit technology that captures carbon emissions from coal-fired power plants

A Summit Power study shows that an East Coast CCS network could boost the UK economy by an estimated £160 billion between now and 2060

Statoil, Shell and Total enter CO2 storage partnership to mature the development of carbon storage on the Norwegian continental shelf (NCS)

UK releases Clean Growth Strategy restarting CCS plans with measures including funding for R&D and international collaboration

Researchers from the University of Liverpool make a significant breakthrough in the direct conversion of carbon dioxide and methane into liquid fuels and chemicals

The Port Arthur large scale CCS project captures and transports its 4-millionth metric ton of CO2

Swiss cleantech company Climeworks partners with Reykjavik Energy to combine direct air capture (DAC) technology for the world's first time with permanent geological storage

The proposed amount in the Norwegian state budget 2018 for developing a full-scale CO2 capture and storage value chain is cut to almost zero

The new Dutch government puts CO2 capture and storage at forefront in climate plan

Deploying current technologies to decarbonise the steel and cement industries is likely not sufficient to meet the Paris Agreement's 1.5°C limit according to a new Climate Action Tracker (CAT) study

BHP Billiton enters a global collaboration with top international universities to accelerate a deeper understanding of CCS in a range of subsurface locations

Alberta carbon capture and storage Field Research Station opens

The U.S. Department of Energy's (DOE) Office of Fossil Energy invests $4 million for the safe storage of CO2 in geologic formations

Battelle completes 15 year CO2 Storage Project at Mountaineer Power Plant

Petra Nova captures more than 1 million tons of carbon dioxide for use in enhanced oil recovery (EOR)

Norway and the port of Rotterdam compete to create the first European chain that will allow CO2 capture from industrial sites to be transported to a storage site offshore

November

Researchers at Imperial College London successfully produce porous boron nitride with four times better adsorption properties than before

Total pledges to dedicate 10% of its R&D budget to CCUS and joins Shell and Statoil on a project to study the world's first commercial carbon storage facility

SaskPower's president says it is "highly unlikely" his company will recommend the government pursue further carbon capture and storage projects in the foreseeable future because they are too expensive

The International Energy Agency held a high-level summit with energy ministers, government officials and chief executives of major energy companies to support a renewed push for investment in CCUS

The University of Surrey develops a new and cost-effective catalyst to recycle two of the main causes behind climate change - carbon dioxide and methane

The Global CCS Institute reiterates its warning that the pace of development across the fledgling carbon capture sector needs to accelerate sharply if the world is to meet the emissions goals set out in the Paris Agreement

December

MIT researchers develop a new system that could potentially be used for converting power plant emissions of carbon dioxide into useful fuels

The National Carbon Capture Center surpasses 100,000 hours of technology testing

The Dutch Government plans to provide €3.1 million of public funding for the construction of CO2 transport infrastructure

Scotland's Acorn Project Project begins a feasibility study after concluding funding from the European Union's funding round Accelerating CCS Technologies (ACT)

Scientists at the U.S. Department of Energy's Idaho National Laboratory develop an efficient process for turning captured carbon dioxide into syngas

Energy Secretary Rick Perry signs a deal with the Saudi Arabian government to allow its Ministry of Energy to collaborate with the U.S. Department of Energy

Global Status of CCS: 2017

The Global CCS Institute's flagship report says Paris climate change targets cannot be met without CCS and presents a vision for how CCS is the conduit to a new energy economy of hydrogen production, bioenergy and CO2 re-use applications.

Launching its Global Status of CCS Report: 2017 today at the 23rd Conference of the Parties (COP23) in Bonn, Global CCS CEO, Brad Page, said renewables alone would not meet international climate change targets, and expert opinion was conclusive that CCS must be part of a suite of clean technologies needed achieve below 2 degree targets.

"In the past year, we have seen significant advances in the number of facilities being deployed and awareness of CCS as a pivotal climate change solution is the highest it has ever been.

"Two large-scale facilities came onstream in the United States, eight moved into various stages of development in China, and in Europe, we have seen realisation that CCS is the only technology capable of decarbonising industry and creating a new energy economy - including hydrogen, bioenergy and 2°C re-use applications.

"However, the challenge still remains to ensure that CCS receives the same consideration and incentivisation as other clean technologies, particularly renewables."

Also speaking at the launch, Lord Nicholas Stern, Chair of the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science, pointed out that the Paris Agreement had been drafted, signed and ratified to date by 169 countries at an unprecedented rate but that there was still a significant gap between the collective national commitments to cut emissions and the goals of the Agreement.

He said: "Most serious analysis has concluded that it will be very difficult to achieve the Paris goals without carbon capture and storage or use."

"We must pursue low-carbon and zero-carbon growth across the board in our cities, infrastructure and land use. Carbon capture and storage or use can play a key role in the transition to low-carbon economic growth and development in many parts of the world."

Echoing these comments, Energy Future Initiative Distinguished Associate, Dr Julio Friedmann, said current policies in most jurisdictions were biased and short-sighted.

"All the benefits commonly cited for renewables and nuclear, such as native industrial support, cost reduction, and emissions reduction, apply to CCS/CCUS as well. Attention must be paid, and speed is needed."

The Global Status of CCS: 2017, includes a commentary from Australia's Ambassador for the Environment, Patrick Suckling, who says

Key highlights from the report

• To reach Paris climate targets:

- more than 2000 CCS facilities will be needed by 2040

-14 per cent of cumulative emissions reductions must be derived from CCS;

• There are now 17 large-scale CCS facilities operating globally, with four more coming onstream in 2018;

• Current CO2 capture is 37 million tonnes per annum (Mtpa) – equivalent to removing eight million cars from the road each year;

• CCS is the only clean technology capable of decarbonising industry – steel, chemicals, cement, fertilisers, pulp and paper, coal and gas-fired powered generation;

• To date, more than 220 million tonnes of anthropogenic CO2 has been safely and permanently injected deep underground;

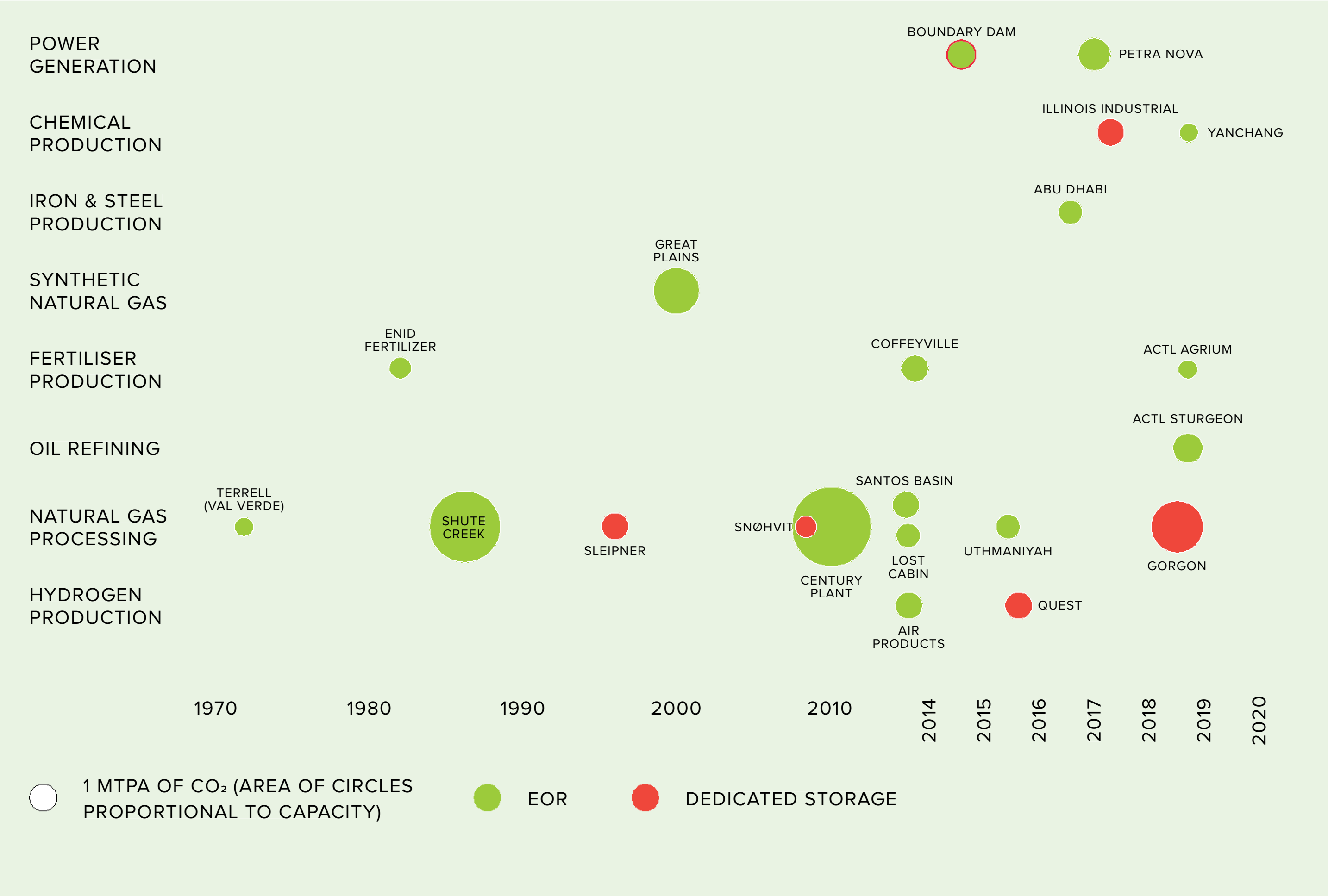
• In Asia and the Pacific (APAC), 11 CCS facilities are in varying stages of development including eight in China;

• In Europe, Middle East and Africa (EMEA), four large scale facilities are operating successfully (two in Norway and two in the Middle East), with two more in early development in the United Kingdom);

• Twelve of the 17-large scale facilities in operation are located in the United States and Canada and two of those came onstream in the past twelve months (Petra Nova and Illinois Industrial);

• CCS is now proving its versatility across five industrial sectors in the United States – natural gas processing, power, fertiliser, hydrogen and biofuels;

• On a like-for-like basis, CCS is cheaper than intermittent renewables and costs continue to fall.



CCS large-scale facilities in operation and construction by industry and operations start date (From Global CCS Institute Global Status of CCS 2017)

we must pull all levers to implement the Paris Agreement.

"Without CCUS, the IPCC says the cost of meeting global targets will double and the IEA says the energy transition would cost US$3.5 trillion more.

Achieving the Paris Agreement's goals will require a renewed focus on international CCS/CCUS collaboration. A renewed push would provide governments with the confidence to develop technology neutral energy and climate change policies that provide incentives to all emissions reduction technologies, including CCUS. This will help to ensure our energy and industrial sectors are affordable and reliable as we transition to a lower emissions future."

Also writing in the Report, the Father of the phrase "global warming", Colombia University Professor, Wallace Smith Broecker, said the dependence on fossil fuels will come to an end and the world will be powered by renewables.

"But as this energy utopia lies many decades in the future, by the time we arrive there, we will be saddled with an atmosphere laden with excess CO2. Garbage brought disease to our streets. We learned to dispose of it. Sewage poisoned our waters. We learned to treat it. CO2 threatens to change our climate. Hence, we must learn how to capture and bury it."

CCS and the new energy economy

CCS is a key component in reconciling the so-called "energy trilemma" – the challenges associated with meeting international climate change commitments, keeping the lights on, and reducing electricity costs, all at the same time.

Inclusion of CCS within a portfolio of low-carbon technologies is not just the most cost-effective route to global decarbonisation, it also delivers energy reliability and lower costs.

As the energy matrix continues to evolve, CCS also facilitates the creation of new energy economies, which are yet to reach their zenith. A good example is the work Kawasaki Heavy Industries is undertaking with Iwatani, J-Power and Shell Japan to scope a hydrogen energy supply chain in Australia's Latrobe Valley.

The opportunity to turn Victoria's brown coal into clean hydrogen is just one example of the new opportunities CCS can create; and to set the stage for a clean energy hub that harnesses jobs and creates a new, decarbonised economy.

The clean energy revolution can also open new opportunities for CCS elsewhere:

• Deployment of CCS can generate economy-wide employment growth in the provision of services (such as project management, engineering, finance, legal and environment), the manufacture of components (such as boilers and turbines), CO2 infrastructure development (such as storage characterisation) and general construction activities

• CCS transforms high-emission industries to low-carbon factories of the future that can prosper under increasingly stringent carbon constraints. This has stimulated several industrial hub and cluster initiatives, most notably in Europe, aimed at maximising economies of scale. These initiatives will retain skilled jobs, create new industries at cluster-points and in Europe's case, give life to a globally significant CO2 storage industry in the North Sea

• Early deployment of CCS, and especially retrofits to existing facilities, avoids the early retirement of highly productive assets. It provides significant benefits to local communities that have grown up around high-emitting industries and face significant dislocation and economic hardship from premature closures.

A vision for an integrated low-carbon energy system

The most affordable and reliable low-emissions electricity system requires everything – fossil based dispatchable power with CCS, and intermittent renewable energy sources with energy storage.

Safe, reliable and affordable electricity is reliant on a suite of technologies to meet changing supply and demand patterns. Intermittent renewable energy with energy storage will be an important part of the future global energy mix but renewable energy alone cannot provide reliable electricity at acceptable cost and risk.

An electricity system with a high penetration of intermittent renewable generation requires back-up and augmentation systems to ensure reliability and resilience. Dispatchable fossil-based generation with CCS requires no additional grid integration costs or risks making it affordable and reliable.

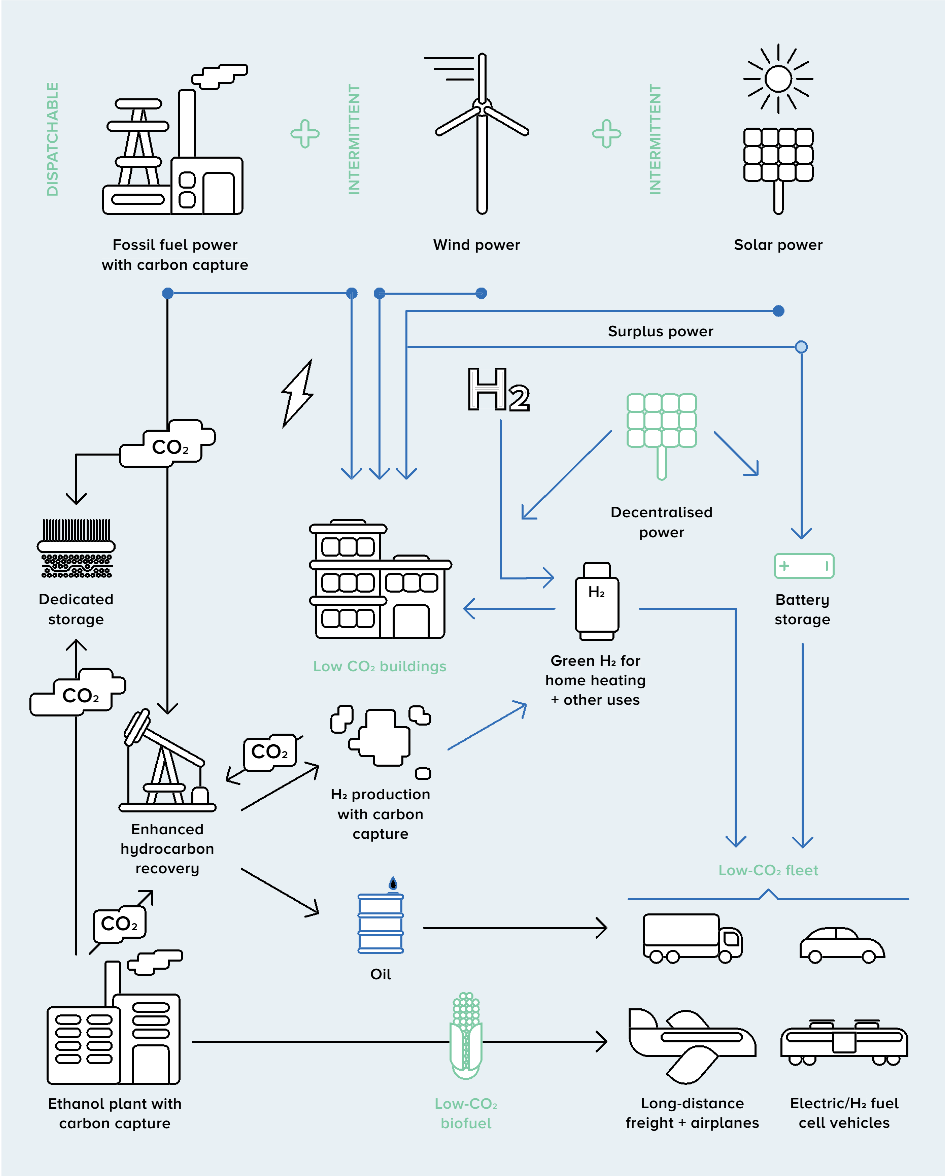
A power system comprising renewables complemented by a suite of decarbonised fossil energy plants will supply electricity day and night, at times of low wind and poor sunlight, and during peak needs.

Electricity generated by this system that is not dispatched can be stored in batteries for other purposes such as powering electric vehicles, which can further be complemented by a fleet of long-distance vehicles operated on fuels from refineries using capture technologies on crude oil produced from CO2- EOR systems.

Such vehicles could also employ hydrogen fuel cells with the hydrogen produced from fossil fuels with CCS. These long-distance vehicles may be transporting chemical or fertiliser products from plants that have captured carbon for permanent storage.

These vehicles will pass through major cities that have redesigned existing natural-gas grids to use "green" hydrogen for home heating purposes backed by significant CCS development.

This integrated energy system enables both renewable and CCS technologies to develop and flourish while also securing the most cost-effective global mitigation response.



Dispatchable fossil-based generation with CCS requires no additional grid integration costs or risks making it affordable and reliable (From Global CCS Institute Global Status of CCS 2017)

More information
www.globalccsinstitute.com

An implementation plan for CCS and CCU in Europe

2017 has seen a number of positive developments for Carbon Capture and Storage in Europe. The EU now needs to put in place a long-term policy framework that incentivises this low-carbon technology in Europe, writes Graeme Sweeney for EurActiv.

Now that COP23 in Bonn has concluded, countries will be turning their attention to the mechanisms and technologies that will enable the achievement of the Paris Agreement. A number of CCS side events took place at COP, indicating that there is a growing realisation that delivering a 2°C scenario, (and particularly a "well-below 2°C" scenario) will be extremely challenging.

CCS will be vital to ensuring the lowest cost route to meeting this goal. Interestingly, Bioenergy with CCS (Bio-CCS or BECCS) emerged several times in the debate regarding negative emissions. It is clear that negative emissions technologies such as BECCS will become increasingly important, as they allow flexibility in harder-to-decarbonise sectors such as aviation.

There is a definite sense that momentum for CCS in Europe has been steadily building over the past year. At COP23, the UK and Canada led a historical alliance to phase out unabated coal across the world, highlighting the crucial role of CCS to meet the Paris Agreement and reduce emissions in a number of sectors.

Both the Netherlands and the UK have emphasised the importance of CCS in their recently published Dutch Coalition Agreement and Clean Growth Strategy respectively. And the Port of Rotterdam is competing with Norway to become the first European CCS cluster, able to capture carbon dioxide from a number of industrial sites to be transported to a permanent storage facility offshore.

At a high level, the European Commission has just published its third list of projects that have received the status of Project of Common Interest (PCI). It is encouraging to note that all four cross-border CO2 transport projects that were submitted to this list have been adopted. PCI projects are able to apply for funding under the Connecting Europe Facility, and this could provide an important source of funding for CCS.

The EU Emissions Trading Scheme (EU ETS) is one of the mechanisms that will enable Europe to decarbonise its industries while meeting its commitments under the Paris Agreement.

Although the EU ETS has so far been unsuccessful in incentivising developers of low-carbon technologies, it is likely to remain a core component of European climate change policy. It is therefore crucial that the current proposals to reform the EU ETS achieve the desired outcome; a higher carbon price that will act as a key driver for low carbon innovation.

Another key plank of the EU ETS reform proposal is the introduction of the Innovation Fund. This replaces previous low-carbon funds such as NER300 and will be an important driver to deliver a number of CCS projects across Europe.

However, on its own, such a fund is insufficient; Europe also needs a coordinated plan to deploy CCS that ensures the EU goal of reducing CO2 emissions by 80-95% by 2050 can be met. Such a plan must be driven by and coordinated between member states if it is to succeed.

Fortunately, a plan was published last week that could deliver the necessary momentum for CCS; the SET-Plan Carbon Capture and Storage (CCS) and Carbon Capture and Utilisation (CCU) Implementation Plan.

The plan was released at a high-level SET-Plan conference that took place in Bratislava last week, and is the culmination of a working group comprised of eleven SET-Plan countries; the Czech Republic, France, Germany, Hungary, Italy, Norway, the Netherlands, Turkey, Spain, Sweden and the UK – as well as industrial stakeholders, non-governmental organisations and research institutions.

The overarching SET-Plan highlights areas where the EU needs to strengthen cooperation to bring new, efficient and cost-competitive low-carbon technologies to market faster while the CCS and CCU Implementation Plan sets out ten targets for CCS and CCU for 2020 (as agreed by the European Commission, SET-Plan countries and industry in the 2016 Declaration of Intent).

Each target is supported by a corresponding activity. These include actions such as delivery of a whole chain CCS power project, delivery of regional CCS and CCU clusters, and establishing a European Storage Atlas.

The publication of this Implementation Plan provides an important – and timely – opportunity to assess how both existing and planned sources of European funding should be designed to ensure the successful deployment of CCS in a number of key European regions. For example, the Innovation Fund and funding programmes under the new Multiannual Financial Framework (MFF) for after 2020.

2017 has seen a number of positive CCS developments in Europe. We now need to put in place a long-term policy framework that incentivises CO2 capture and storage, facilitating an environment in which follow-on projects and investments can take place.

Above all else, it is vital that Europe introduces the investment and financing models to realise the cross-border CO2 transport and storage infrastructure that will create CCS hubs. Such hubs will transform key European regions into sustainable industrial zones, aligning regional growth with cost-effective emissions reductions whilst safeguarding and boosting vital European industries.

More information

Graeme Sweeney is Chairman of the European Zero Emission Technology and Innovation Platform (ZEP), a coalition of stakeholders united in their support for CO2 Capture and Storage (CCS) as a key technology for combating climate change.

www.zeroemissionsplatform.eu

www.euractiv.com

Evaluation of the NET Power low carbon power process

NET Power's supercritical CO2 power cycle technology has the potential to be a gamechanger for power generation with carbon capture. Modelling analysis by the Energy Technologies Institute shows that it has the potential to acheive greater efficiences than current processes.

NET Power's 50MWth demonstration unit of their radical new gas-fired power plant design targets power production with CO2 capture at a similar cost to a conventional Combined Cycle Gas Turbine (CCGT) without post combustion abatement, and in particular targets an efficiency of 58.9% LHV[1].

If realised, the technology could enter the power market and offer carbon capture at zero additional cost, and the cost for fully built up CCS systems would be significantly reduced, consisting only of the much smaller costs associated with CO2 transportation and storage. Additionally the technology could offer CO2 for use in Enhanced Oil Recovery (EOR) application at a very attractive cost.

Key headlines

• NET Power technology has the potential to be a gamechanger.

• Modelling analysis confirms that NET Power's supercritical CO2 power cycle has the potential to deliver carbon capture at efficiencies higher than conventional amine solutions.

• Some unpublished innovations which NET Power are protecting as trade secrets are needed to make the technology as cost efficient as an unabated CCGT, which is still improving rapidly.

• The technology is immature and has multiple development hurdles to overcome and therefore it is likely to take several years before it is commercially available at scale. It is therefore likely to be best suited for deployment once other elements of CCS have been de-risked (i.e. transport and storage) rather than in a First of a Kind full scale development.

In 2015, the IEAGHG produced a report[2], which included an assessment of the NET Power technology, based on publically available information. IEAGHG modelling had concluded that the technology was around 55.1% LHV efficient, and in a commentary section in the report, NET Power explained that a combination of better quality vendor data and some trade secrets in their design (neither of which were available to IEAGHG) could bridge the gap to the target figure of 58.9%.

The ETI carried out simplified modelling of the NET Power process in 2013 and 2014, again using publically available information. This work was refreshed after the IEAGHG report was issued, incorporating some of the IEAGHG assumptions to ease comparison, and this paper reports these largely corroborative findings as an additional independent reference.

The ETI conclusion is that the NET Power technology is at least c.55% efficient, and that NET Power's commentary on how their proprietary data and trade secrets can improve this to 58.9% applies to the ETI analysis also.

Performance assessment of the NET Power cycle

The new power cycle is shown in Figure 1. Supplies of oxygen from an Air Separation Unit (ASU) and natural gas (diluted with CO2) are fed to a high-pressure combustor (300 Barg) and the hot combustion products of CO2 and water are expanded through a gas turbine to 30 Barg. The water produced by combustion is condensed, and the CO2 which remains is pressurised to a supercritical state, pumped back up to 300 Barg, and sent back to the combustor where it is used both to recycle turbine exhaust heat within the system and as coolant for controlling combustor temperatures. A slip stream is purified cryogenically and pumped to storage or sent directly for use in EOR assets.

There is no steam cycle – this is replaced by CO2 as the main working fluid.

Features of this process include:

• Using a Gas Turbine (GT) – which under these process conditions is inherently highly efficient.

• Recycling a dominant flow of CO2 as the combustor coolant which follows an energy path shown in Figure 2.

• Recuperating high levels of heat from the CO2 recycle in efficient exchangers.

• Using low-grade heat efficiently, of which

1. Allam, RJ, Palmer, M, et al, (2013). High efficiency and low cost of electricity generation from fossil fuels while eliminating atmospheric emissions, including carbon dioxide [online].
Available at: http://www.sciencedirect.com/science/article/pii/S187661021300221X
2. IEAGHG (2015). Oxy-Combustion Power Plants 2015/05. [online]. Available at: http://ieaghg.org/conferences/49-publications/technical-reports/599-2015-05-oxy-combustion-turbine-power-plants

there is a shortage in the process.

• Using the latest alloys, including new high Nickel alloys[3], at the top end of their performance limits.

• Developing new pieces of equipment[4] - a new combustor, turbine and possibly heat exchanger designs – each of these an achievement in its own right.

The following are key to achieving high efficiency:

• Maximising the work taken from the turbine expansion '2', and minimising the work input in the compression and pumping sections shown after the coolers at '4' and '5' in Figure 2.

• Providing additional low/medium grade heat at '6', plus full recuperation of heat ('7&3'), so that the fuel combustion at '1' adds heat at a high average temperature.

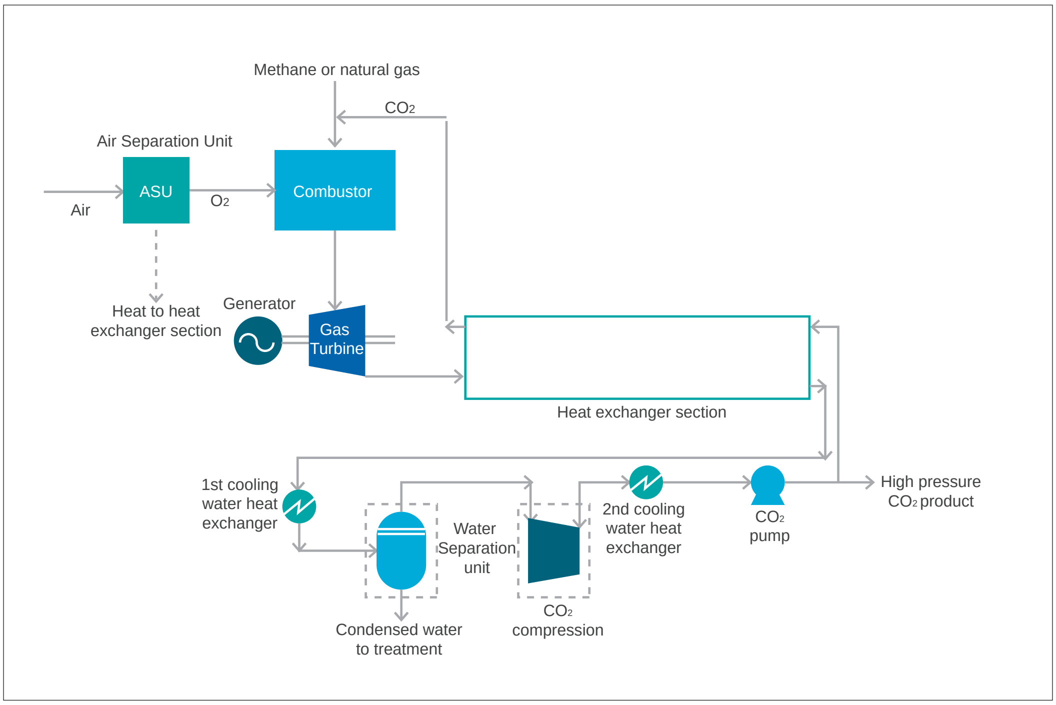


Figure 1 - the NET Power process (Source: ETI Perspective)

ETI analysis

ETI undertook a short work program to check the validity of NET Power's claims. Process modelling was carried out by Foster Wheeler (FWEL) in Aspen Hysis and by PSE in gCCS.

Process modelling showed that:

• For an idealised cycle (100% methane feed, no pressure drops etc.), NET Power's efficiency claims in its patent applications could be met quite comfortably.

• The high efficiency of the process is susceptible to:

a) any build-up of inerts in the CO2 loop.

b) loss of performance in any of several state of the art equipment items, including rotating machinery, heat exchangers, the ASU etc.

• There is upside potential from:

a) having cold cooling water available.

b) improvements to metallurgy allowing higher temperatures and pressures in the heat exchange train.

c) the ability to upgrade low-grade heat to power at high efficiency, if a low cost heat supply is available from other sources or auxiliary conventional generation.

Relaxing the temperature constraints on the hot end heat exchanger, and allowing the turbine inlet temperature to rise by 50°C to 1200°C increased the plant efficiency by 1.1% LHV. Increasing the turbine outlet pressure whilst maintaining the inlet conditions at base case values (300 Barg and 1150°C) also raised efficiency, as the reduction in compression energy was higher than the loss of gross turbine output.

Alloy development should therefore remove constraints on efficiency, but will also improve the efficiency of conventional technologies. Historically this has taken many years and use of these alloys not only increases equipment costs, but requires more sophisticated operations, monitoring and maintenance programs.

The thermal energy needed to cool and heat high pressure, low temperature CO2 is relatively high i.e. it has a high specific heat. In a process where high recuperation is essential to efficiency, aggressive use of all low-grade heat streams is important. The ASU air compressors are run without intercooling so that hot air is available for the process. Any other form of low and medium grade heat to help reheat the CO2 recycle stream to a temperature close to the turbine outlet temperature helps efficiency in most ETI model runs.

For those cases where there was insufficient heat to close the hot end approach temperatures (the majority), every 10MWth added from the ASU (or other source) provided over 6 MWe of power. This also suggests that integrating the power station into an industrial plant or other power unit with surplus low-grade heat will be advantageous.

Since compressing CO2 takes more energy than pumping it, efficiency can be improved by condensing CO2 with the coldest medium available and minimising compression. Seawater, which has a summer peak temperatures of 15°C and an annual average of 10°C in

3. Toshiba Corporation Power Systems Company (2013). The NET Power cycle and the combustor and turbine development [online].
Available at: http://anlecrd.com.au/wp-content/uploads/2016/08/4.TheNETPowerCycleandtheCombustorandTurbineDevelopment-Nomoto.pdf
4. Allam, RJ, Palmer, M, et al, (2013). High efficiency and low cost of electricity generation from fossil fuels while eliminating atmospheric emissions, including carbon dioxide [online].
Available at: http://www.sciencedirect.com/science/article/pii/S187661021300221X

North East England, was examined as alternative cooling water supply. The seawater case gained 1.5% efficiency, for a 4°C decrease in coolant supply temperature.

The IEA GHG report studied a different range of sensitivities. Where similar themes were examined, the results were directionally the same and of the same order of magnitude.

Modelling by the ETI, without the benefit of vendor information, but estimating all process losses, could achieve c.55% LHV efficiency. NET Power claim that this is the base level performance achievable using publically available information, without the benefit of several years of development and optimization experience with their cycle.

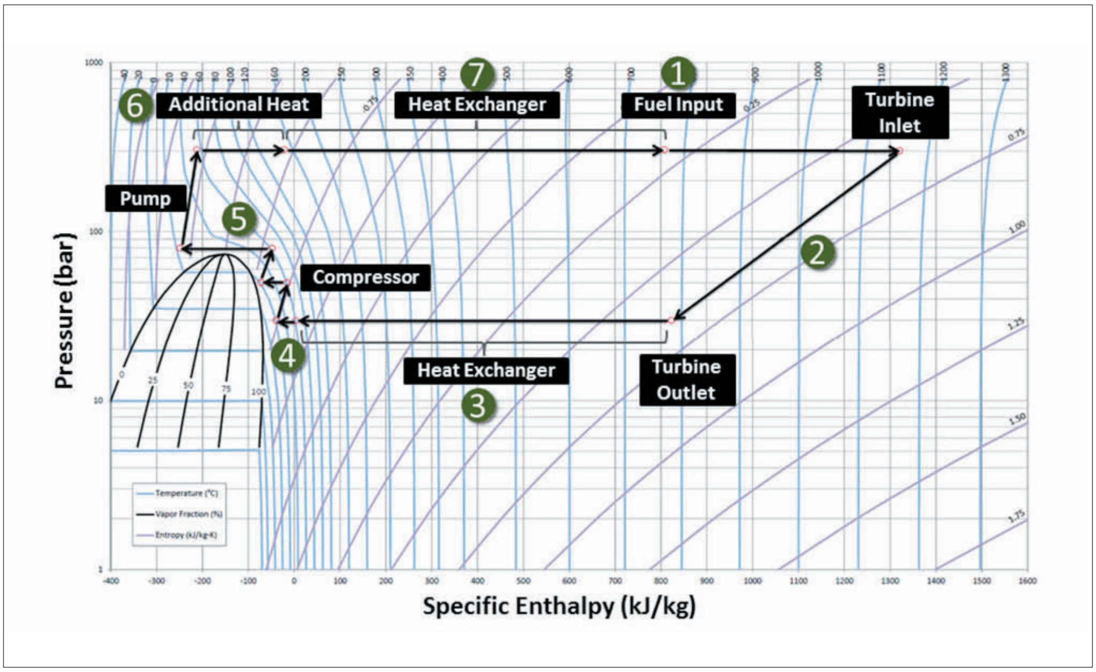


Figure 2 - a pressure enthalpy diagram for the NET Power cycle in pure CO2 (courtesy NET Power)

Commercial entry to the market

The NET Power technology is technically immature, in that multiple new pieces of complex equipment have to be designed and constructed, some of which uses metallurgy which has only relatively recently been commercialised.

The consortia currently completing the construction of the 50MWth unit (CB&I, Exelon, NET Power, 8 Rivers Capital) can benefit from a large internal source of expertise and nationally funded technical supercritical CO2 communities that have developed various themes of the technology in laboratory and pilot plants. However, a full cycle NET Power pilot plant has not yet been built, and development and claims are based largely on modelling, so it will take several years for a fully commercial offering to materialise.

In the meantime, competition from post combustion carbon capture technology is getting stiffer, with proven new class H CCGTs combined with engineered amine capture plants offering efficiencies of 52% LHV, each CCGT train having double the power output of the expected early oxy turbine sizes.

If NET Power fall short of their targets, and the efficiency of the NET Power process is less than an unabated CCGT (now 62% LHV), the technology may not gain the rapid commercialisation offered by the open power market without garnering additional value from the captured CO2. Instead, it could compete in the CCS and Enhanced Oil Recovery markets with other new technologies, some of which are retrofitable to existing power stations.

Energy system modelling showed that if NET Power meet their targets, the technology could significantly displace others by 2040 and increase deployment of CCS at the expense of other low carbon options. Even if lower performance is achieved in its early years (e.g. that in Oxy-Combustion Turbine Power Plants, IEAGHG Report 2015/5) the technology could still warrant deployment.

The 50MWth demonstration plant under construction in Texas to test the full cycle, includes the new combustor and turbine design and use of modern high nickel alloys. The control scheme for the plant will also be tested for the first time. NET Power are targeting deployment of a first commercial scale (300MWe) plant by 2020.

Summary

If they meet their targets, NET Power will license a game changing technology. It has no solvent toxicity to manage, an extremely small footprint, and an impactful efficiency improvement over post combustion capture. It could enter the broader power market if it can keep pace with conventional CCGT improvements, and the CCS market with little or no subsidy requirement.

The technology is still immature and faces several challenges on equipment design and operation. Although testing at scale is under way, it may be several years before NET Power can fully demonstrate an attractive package to the market.

Successful development of full chain CCS projects based on conventional technologies will reduce the overall risk of CCS investments and therefore its cost. These technologies are 'raising the bar' through improvements from deployment, but will derisk CCS chains, and so create better conditions for market entry by novel technologies such as NET Power's.

More information

The full report is available for free from the Energy Technologies Institute.

www.eti.co.uk

www.netpower.com

www.psenterprise.com

CCS gets boost from Scotland's first Energy Strategy

Scottish Carbon Capture & Storage welcomed the Scottish Government's first Energy Strategy which includes CCS as a priority.

The strategy sets out six priorities in a holistic approach to providing Scotland with low-carbon heat, power and transport.

SCCS said it welcomes the inclusion of carbon capture and storage (CCS) in one of the six priorities and, therefore, the recognition of its vital role in tackling our carbon emissions across the whole economy – decarbonising gas and industry as well as back-up thermal generation.

As mentioned in the strategy, the delivery of CCS will be a vital part of a just transition for the oil and gas industry. It can provide the bridge from fossil fuel dependency to a zero-carbon future. A number of reports have already shown that CCS can bring economic benefits and jobs to Scotland. The strategy rightly points to the role of CCS in preparing the sector and its workforce for a positive role in Scotland's future energy system.

However, it needs to explicitly mention the current tension between decommissioning ambitions and the need to retain existing pipeline infrastructure for repurposing to carbon dioxide (CO2) transport. This crucial issue alluded to under CCS but is absent from the discussion of decommissioning.

We would suggest that applications for funding through the Decommissioning Challenge Fund need to be assessed against criteria that properly take into account the potential for re-use of the infrastructure, so that opportunities for repurposing are not lost because of a current lack of business case.

We would also like to emphasise the important role that Scotland's oil and gas workforce will play in developing CO2 transport and storage – the skills and experience in that sector will be vital to maximising the opportunities that CCS can bring to Scotland.

We are pleased to see the inclusion of a 50% renewables target for all energy. The CCS sector has consistently pointed out that the technology is complementary to renewables rather than being in competition with it. And we look forward to working closely with the Scottish renewables sector and environmental NGOs in realising this target.

We also welcome the recognition that planning has a role to play in delivering the energy strategy and supporting CCS. Although energy is a reserved matter, many of the policy levers that can move energy in the right direction – such as planning – rest with the Scottish Government. This underlines the Scottish Government's commitment to doing everything in its power to deliver CCS in Scotland and also influence the UK Government on its policy. However, we must not lose sight of the need for firm policy and financial commitment from Westminster.

The forthcoming consultation on a publicly-owned energy company is to be applauded. But we wonder if this could include an embedded a low-carbon quality standard, which would provide a boost for low-carbon electricity.

It goes without saying that we welcome Energy Minister Paul Wheelhouse's recognition of Scotland's academic expertise and we look forward to continuing to work with Scottish Government on developing and delivering a CCS industry, not just for the UK but worldwide.

Other actions that we welcome in the strategy include support for the Acorn CCS project in north east Scotland, which could see the delivery of a cost-effective, small-scale CCS infrastructure, which can eventually be built out to handle carbon emissions from multiple sources, including Europe.

Prof Stuart Haszeldine, SCCS Director, said, "The Scottish Energy Strategy shows that, if you look at the whole picture, more and diverse actions are needed, including the capture, re-capture and secure burial of waste carbon, which is causing climate change. Analysing all the energy sectors across Scotland, using real data, takes us to the reliable conclusion that we need to be more efficient with our energy supplies, we need to produce clean energy from different technologies but we also need CCS as part of that mix - to supply clean low-cost hydrogen, to decarbonise industry and clean up fossil fuel use in our transition to a zero-carbon future."

More information

www.sccs.org.uk

www.gov.scot

IEA holds global summit on carbon capture

The International Energy Agency held a high-level summit with energy ministers, government officials and chief executives of major energy companies to support a renewed push for investment in carbon capture, utilisation and storage.

The CCUS Summit, held ahead of the IEA's 2017 Ministerial Meeting, was co-chaired by Rick Perry, the United States Secretary of Energy and Dr Fatih Birol, the IEA Executive Director. Participants included ministers and top government officials from Australia, Canada, Japan, Mexico, Norway, Poland, The Netherlands, the United Kingdom and European Commission. Industry representatives included CEOs and senior executives from ExxonMobil, Royal Dutch Shell, BP, Statoil, Chevron, Total Glencore, Suncor Energy, GE Power, Dow Chemical, Mitsubishi Heavy Industries, and Port of Rotterdam.

"Today's summit at the IEA provided a unique opportunity to gather with my counterparts and industry leaders to discuss the future of CCUS," said Secretary Perry. "While we come from different corners of the world, we can all agree that innovation, research, and development for CCUS technologies can help us achieve our common economic and environmental goals."

"This is the highest level of industry and government engagement that we have seen on CCUS," Dr Birol said. "Global energy leaders recognise that urgent action is needed to support this essential technology and are demonstrating their preparedness to work together to achieve this."

CCUS offers an important and unique technology solution to deliver the deep emissions reductions needed in industry and the power sector, while also supporting energy security and protecting substantial capital investments in existing infrastructure. But investment is lagging even as the global energy transformation gains momentum.

New analysis from the IEA finds that large-scale CCUS projects have received around USD 10 billion in capital investment around the world. Low-carbon energy investments received USD 850 billion last year alone with just 0.1% going to CCUS.

Five keys to unlock CCS investment

The IEA offered five priority areas of action to boost CCS investment - "Five Keys to Unlock CCS Investment." These are:

• Harvest "low-hanging fruit" to build CCS deployment and experience from the ground up.

• Tailor policies to shepherd CCS through the early deployment phase and to address the unique integration challenges for these facilities.

• Target multiple pathways to reduce costs from technology innovation to progressive finance arrangements.

• Build CO2 networks and accelerate CO2 storage assessments in key regions.

• Strengthen partnerships and cooperation between industry and governments.

The IEA will maintain a strong focus on CCUS in the Agency's clean energy technology work and analysis.

The policies and programmes that have been successful in supporting a wide range of low carbon energy investments will increasingly need to be tailored and applied to CCUS if energy and climate goals are to be achieved.

"The under-investment in CCS is deeply concerning," said Dr Birol. "We know that we face an unprecedented challenge in meeting climate goals. Without CCS, this challenge will be infinitely greater. We also know that this is essentially a policy question."

Ten of the 17 large-scale CCUS plants currently in operation have been commissioned in the last five years and include key applications in coal-fired power generation, oil sands processing and steel production. While the United States was a pioneer in CCUS and has continued its leadership, including with the recent commissioning of the Petra Nova and Illinois Industrial CCS projects, the project fleet is now much more diverse and a truly global effort is underway.

CCUS projects are today operating or under construction in Australia, Brazil, Canada, the People's Republic of China, Norway, Saudi Arabia and the United Arab Emirates. Smaller-scale projects are underway throughout Europe and in Indonesia, Japan, Korea and Mexico.

The IEA has published an analysis of the work that needs to be prioritised to achieve CCS deployment, titled, "Five Keys to Unlock CCS Investment." (see above)

It calls for a renewed international commitment to CCS to revive momentum in the project pipeline, maximise the global impact of existing investments, and build a solid foundation for the rapid and immediate ramp-up of CCS deployment.

More information

www.iea.org

Projects and policy news

Acorn CCS project gets under way

actacorn.eu

Scotland's Acorn Project Project has begun a feasibility study after concluding funding from the European Union's funding round Accelerating CCS Technologies (ACT).

The Acorn CCS project is a phased full-chain project in North East Scotland, which will transport and store CO2 captured initially from the St Fergus gas processing terminal. The CO2 will be transported offshore and injected deep underground for permanent storage in a saline formation. Later phases will store CO2, a greenhouse gas, from other sources.

The ACT Acorn study is being led by Pale Blue Dot Energy with project partners Scottish Carbon Capture & Storage (University of Aberdeen, University of Edinburgh and Heriot-Watt University), University of Liverpool, Bellona (Norway) and Radboud University (The Netherlands).

The study will demonstrate the commercial and regulatory aspects of CCS project development in the UK. This would include the commercial aspects of transferring oil and gas infrastructure for use in CCS, the implementation of CO2 storage permits and development of funding and risk allocation aspects of CCS projects.

Researchers will develop a full-chain business case and economic model as well as pinpoint the best North Sea geological CO2 storage site for the project. They will also recommend policy that could support a just transition to a decarbonised future in regions dependent on fossil fuel industries and identify tools and methodologies for public engagement.

CCS has significant potential to generate economic value and create jobs through the delivery of future projects in the UK. The recent report Clean Air-Clean Industry-Clean Growth; How Carbon capture will boost the UK economy concludes that CCS will bring £129 billion in societal and economic benefits to the UK. The UK is well placed, with CCS supply chain skills, to address this emerging market.

Aage Stangeland, of Research Council of Norway, which co-ordinates the ACT fund, said: "The Acorn project looks very promising. The project has the potential to be the start of a CCS value chain in the North Sea. This could make a significant contribution to wide deployment of CCS in Europe."

Steve Murphy, project director, of Pale Blue Dot Energy said: "Acorn is an exciting step forward for CCS in the UK, especially after several false starts in recent years. Acorn starts on a small scale, re-using existing oil and gas infrastructure. This is essentially a commissioning phase for a project that could see millions of tonnes of CO2 stored as Acorn expands to include emissions from Central Scotland, from future hydrogen produced at St Fergus and the potential import of CO2 to Peterhead Harbour. We want to encourage the replication of the Acorn project worldwide, and one of our key objectives is to engage with low-carbon stakeholders in Europe and further afield to disseminate lessons learned and tools created."

ELEGANCY – accelerating CCS deployment by combining CCS and hydrogen

www.elegancy.no

The project will investigate how hydrogen production can be accommodated in a CCS system, thus reducing CO2 emissions.

ELEGANCY is a research project involving consortia from the UK, Norway, the Netherlands, Germany and Switzerland, supported by ACT (Accelerating CCS Technologies, an ERA NET Cofund) and national governments, involving 22 partners from seven European countries coordinated by SINTEF Energy Research.

It is one of eight new ACT (Accelerating CCS Technologies) projects funded by national funding agencies and the European Commission. ELEGANCY will perform scientific research on selected topics within hydrogen-CO2 separation and CO2 transport, injection and storage. To enable application of this research, ELEGANCY will develop an open-source design tool for fully integrated hydrogen-CCS chains.

As the only technology that can substantially reduce CO2 emissions from fossil fuels, carbon capture and storage (CCS) will be essential if the UK is to meet the goals of the Paris Agreement. CCS is also the only means of achieving deep emissions cuts in industries such as steel, cement and petrochemicals.

However, there is a large disconnect between policy ambitions and technology readiness, and industrial uptake. This is mainly due to the lack of a business model: costs are immediate, but the benefits are long term. Similarly, the introduction of hydrogen (H2) as a low-carbon fuel for heating, cooling, transport and industrial processes has been slower than desired. However, as the natural gas (NG) reforming for H2production also produces CO2 using existing or new processes, this can provide the economic driver needed to fast-track commercial deployment of CCS.

The ELEGANCY project has three key objectives:

1) to facilitate decarbonisation of power, heating and transport based on an existing fuel and infrastructure

2) to develop a commercial model for industrial CCS

3) to broaden public awareness of CCS

ELEGANCY includes consideration of large-scale CO2 transport and storage infrastructure for use by other sectors, as well as infrastructure for the rapid introduction of H2 as an energy carrier, thus also opening the door for H2 generated from spare capacity in renewable sources.

It will also enable Europe to export extensive knowledge, products and technologies worldwide. ELEGANCY will apply its research findings, technologies and tools to five national case studies in order to identify cost-effective opportunities for H2-CCS for each country represented in the project, providing key input for policy makers. ELEGANCY partners are world leaders in their respective fields, comprising not only highly-respected research institutions and legal experts, but technology vendors, NG grid operators and international energy and petrochemical companies.

Within ELEGANCY, Imperial will contribute ground-breaking new research in CO2 storage, developing an open-source modelling framework for the design and evaluation of integrated H2-CCS chains, and applying the research findings to a detailed national case study. The research will be carried out by a multi-disciplinary team led by Professor Martin Trusler, Professor Nilay Shah, Dr Ronny Pini (Department of Chemical Engineering), Dr Sam Krevor (Department of Earth Science and Engineering) and Dr Niall Mac Dowell (Centre for Environmental Policy).

Four jurisdictions partner on carbon capture research, cooperation and Knowledge Sharing

www.saskatchewan.ca

Saskatchewan, Montana, North Dakota and Wyoming today jointly signed a memorandum of understanding (MOU) on Carbon Capture, Utilization and Storage (CCUS).

In the MOU, the four governments express a mutual desire to reduce greenhouse gas emissions while aiming to improve strategic and diverse energy production. Accordingly, they will collaborate on CCUS knowledge sharing and capacity building as well as policy and regulatory expertise in the fields of carbon dioxide capture, transportation, storage and applications such as enhanced oil recovery.

With an estimated 1,600 coal-fired power plants planned or under construction in 62 countries around the world, CCUS has been identified as a key technology in the global effort to reduce greenhouse gas emissions. In China alone, 922,000 megawatts of power is produced from coal-fired plants, about seven times Canada's total electrical generating capacity.

"Our four energy-producing jurisdictions are committed to sharing knowledge on this important technology so that we can manage greenhouse gases responsibly while ensuring our economies continue to grow," Premier Brad Wall said. "As a world leader in the advancement of CCUS technology, Saskatchewan has much to contribute. SaskPower's ground-breaking Boundary Dam 3 project is the world's first commercial power plant with a fully-integrated post-combustion carbon capture system, and an excellent example of what is possible if we embrace CCUS."

Wall noted that Boundary Dam 3 captured 85,000 tonnes of carbon dioxide (CO_2) in October, the highest monthly total since the carbon capture unit began operations in October 2014. Altogether, BD3 has captured 1.75 million tonnes of CO_2 since start up, the equivalent emissions of 440,000 vehicles.

According to the International Energy Agency (IEA), CCUS could deliver 13 per cent of the cumulative emissions reductions needed by 2050 to limit the global increase in temperature to 2°C.

"As states and as a nation we need to prioritize research into carbon capture if we are going to confront climate change and take full advantage of our existing resources," Montana Governor Steve Bullock said. "Done right, we can drive economic growth and create and maintain good-paying jobs across the region. The bottom line for me is we should be in control of our energy futures, and that includes the important work accomplished through this MOU."

"By harnessing our collective expertise and technology, we can show it's possible to grow energy production and the economy while reducing emissions through increased innovation rather than expanded regulation," North Dakota Governor Doug Burgum said. "In a carbon-constrained world, improved CCUS technologies will enable our lignite industry to provide reliable baseload generation for decades to come, while also potentially helping us recover billions of barrels of oil through enhanced recovery methods – turning carbon dioxide from an unpopular byproduct into a valuable product."

"This MOU builds upon the investments Wyoming has made in energy research and carbon management," Wyoming Governor Matt Mead said. "Wyoming is home to groundbreaking research at the School of Energy Resources, the Integrated Test Center and the Enhanced Oil Recovery Institute. We are also working on a first of its kind project to develop statewide pipeline corridors that further CCUS efforts. Wyoming looks forward to the opportunity, under this MOU, to work with Saskatchewan, Montana and North Dakota to find ways to commercialize carbon technologies and ensure the long-term viability of our fossil energy resources."

The parties hope the information sharing and exchange will both expand their respective use of CCUS and lead to its potential wider deployment in North America and internationally.

The three-year MOU will also encourage the immediate engagement of CCUS-related organizations in the four jurisdictions, prioritize joint co-operative projects and ensure a formal evaluation process of activities and accomplishments.

Great Plains Institute releases report on CO2 capture from ethanol

www.betterenergy.org

The report is titled, "Capturing and Utilizing CO2 from Ethanol: Adding Economic Value and Jobs to Rural Economies and Communities While Reducing Emissions."

The State CO_2-EOR Deployment Work Group has released a new report that explores the opportunities and potential for expanded energy production, economic development and emissions reductions from capturing and utilizing carbon dioxide (CO_2) from ethanol production.

The State CO_2-EOR Deployment Work Group works to expand carbon capture from power plants and industrial facilities, such as ethanol plants, for use in enhanced oil recovery with geologic storage (CO_2-EOR).

The report focuses on the role of carbon capture in the ethanol industry and outlines measures needed at the federal and state levels to foster further commercial deployment.

The analysis in the report shows that revenue from the sale of CO_2 for EOR, combined with the proposed federal 45Q tax credit and complemented by eligibility for tax-exempt private activity bonds and master limited partnerships, could enhance the feasibility of deploying carbon capture from ethanol production and the necessary pipeline infrastructure to transport that CO_2 to oilfields where it can be put to beneficial use and stored.

Governors Matt Mead (WY) and Steve Bullock (MT) launched the Work Group in 2015, which released a comprehensive set of federal and state incentive policy recommendations for carbon capture in December 2016 – Putting the Puzzle Together: State & Federal Policy Drivers for Growing America's Carbon Capture & CO_2-EOR Industry – a white paper outlining recommendations for national CO_2 pipeline infrastructure in February 2017 - 21st Century Energy Infrastructure: Policy Recommendations for Development of American CO_2 Pipeline Networks and a report recommending policies to enable power plants with carbon capture to compete cost-effectively in wholesale power markets entitled Electricity Market Design and Carbon Capture Technology: The Opportunities and the Challenges in June 2017.

7th Carbon Sequestration Leadership Forum Ministerial Meeting

The event, co-chaired by the United States and Saudi Arabia and held in Riyadh, began with discussions on policy and technical aspect of CCS with representatives from more than 20 countries and culminated with a day-long conference of energy ministers, including U.S. Energy Secretary Ernest Moniz.

On December 5, 2017, U.S. Assistant Secretary for Fossil Energy Steven Winberg led the Policy Group meeting at the 7th Ministerial Meeting of the Carbon Sequestration Leadership Forum (CSLF). U.S. Secretary of Energy Rick Perry represented the U.S. as co-chair of the ministerial meeting.

The CSLF is a 26-member international initiative focused on the development of cost-effective carbon capture, utilization, and storage (CCUS) technologies. Twenty-five countries and the European Commission are represented in the organization, which holds a ministerial-level conference every two years.

The UAE, represented by Minister of Energy Suhail Al Mazrouei, hosted and co-chaired this year's conference.

The CSLF, which fosters international collaboration to address key challenges to CCUS technology development and deployment, consists of a Technical Group chaired by Norway and a Policy Group chaired by the United States, which is responsible for addressing the legal, regulatory, and financial issues associated with CCUS technologies. During the meeting of the Policy Group, Assistant Secretary Winberg noted the "encouraging movement toward increased international support for CCUS." He pointed out, however, that the technologies still faced hurdles to commercialization. "That means the CSLF still has important work to do," he said.

In addition to leading the Policy Group, Assistant Secretary Winberg spoke about the opportunities for CCUS in the United States during a panel session chaired by Secretary Perry. He addressed successful CCUS projects supported by the Department of Energy, including the Air Products and Petra Nova projects. He also pointed out that CCUS commercialization requires effective policies that encourage investment in the technologies. "More robust policies for CCUS would provide financing and market certainty needed for deployment, and support to develop CCUS supply chains, commercial infrastructure, and private investment," he said.

The 7th Carbon Sequestration Leadership Forum Ministerial Meeting was held in Saudi Arabia and was attended by senior representatives from 25 countries and the EU

At the conclusion of their discussions, the Ministers and Heads of Delegation of the CSLF Members released a communiqué detailing eight key actions agreed upon in the meeting as being necessary for global CCUS technology deployment. The communique highlighted continued collaborative research and development as the optimal path for disseminating best practices for CCUS technology development and deployment globally.

Communiqué: Advancing the Business Case for CCUS

The Ministers and Heads of Delegation of the CSLF Members said they were greatly encouraged by the progress made in the research, development, demonstration and global deployment of carbon capture, utilization, and storage (CCUS).

"We met today to discuss how we can expand and strengthen the business case for CCUS globally. Collectively, we have the opportunity, working with industry and others, to accelerate CCUS deployment with strong global commitments and supportive government policies built on existing national circumstances, priorities, and obligations."

According to the International Energy Agency, the use of fossil fuels is projected to continue well into the future, underscoring the critical need for CCUS in the power sector. Moreover, CCUS is a key option for deep CO2 emission reduction from process industries such as refineries, the chemical sector, and cement and steel production. Therefore, CCUS technology will be an important contributor to the global clean energy transition.

Since we last convened in 2015, international collaboration on CCUS has continued to expand and more projects have commenced operations, including the world's first large-scale bio-energy with CCS project in the United States, and the first fully-integrated CCUS project in the steel industry in the United Arab Emirates. There are now 17 large projects in operation and four coming on stream in 2018, which together will more than double the number of operational projects since 2010. Combined, these projects are capable of capturing 37 million tonnes of CO_2 per year. Their geographic distribution, scale, and technical diversity demonstrate we are gaining global CCUS experience and creating a strong technical, policy, and regulatory foundation for CCUS in the power and industrial sectors, both onshore and offshore. We must, however, build upon our current successes and do more to rapidly expand the global CCUS portfolio.

"We, the Ministers, are committed to the successful global deployment of CCUS. We will continue to work together with the private sector to drive down the costs of CCUS and accelerate global deployment by identifying new commercial models and develop the next generation of CCUS technology."

Key Actions Needed for CCUS Deployment

1. We will work together to ensure that CCUS is supported as part of the suite of clean energy technologies, along with other low emission energy solutions. We will give CCUS fair consideration in clean energy policies and resource commitments, while also recognizing that the appropriate design of a CCUS policy framework will vary among countries and across industries.

2. We will leverage the success of operational CCUS projects worldwide while emphasizing the urgency of developing and executing new CCUS projects in the future. Industrial processes offer opportunities for early CCUS projects and should continue to be pursued. We will continue to encourage new investment for additional CCUS projects and a steady flow of new CCUS projects to the pipeline.

3. We encourage the development of regional strategies that strengthen the business case for CCUS and accelerate deployment. We will support regional approaches that take advantage of business opportunities, common policy frameworks, as well as regional infrastructure and geologic conditions to promote CCUS deployment. Governments should consider supporting and investing in CO_2 infrastructure onshore and offshore to facilitate commercial CCUS deployments and enable other value added opportunities such as Enhanced Oil Recovery (EOR).

4. We will explore new utilization concepts beyond CO_2-EOR that have the potential to add commercial value. We encourage development of novel utilization technologies that can help improve economics, while continuing to support geologic storage as the most important option long term.

5. We will support collaborative research and development (R&D) on innovative, next-generation CCUS technologies with broad application to both the power and industrial sectors. This includes work under the Mission Innovation carbon capture challenge, which is looking at breakthrough technologies at early stages of technology readiness, as well as opportunities for closer engagement on R&D through other multilateral and bilateral efforts.

6. We will expand stakeholder engagement and strengthen links with other global clean energy efforts to increase public awareness of the role of CCUS and build momentum. In addition, we will continue to engage industry, academia, the financial community, non-governmental organizations, and other stakeholders to drive business case discussions forward. We will continue to work closely with multilateral initiatives such as Mission Innovation, the Clean Energy Ministerial, the International Energy Agency, and the IEA Greenhouse Gas R&D Programme (IEAGHG), as well as with the stakeholder community to advance CCUS research, development, and global deployment.

7. We will increase global shared learnings on CCUS by disseminating best practices and lessons learned from CCUS projects and strengthen coordination on R&D efforts globally. Shared learnings can greatly enhance future projects, particularly when first-of-a-kind technologies and/or regulatory frameworks are successfully implemented, including for offshore developments.

8. In recognition of the importance of community support, we will continue to engage the public on CCUS and look for ways to communicate effectively.

Technology Roadmap

The Carbon Sequestration Leadership Forum (CSLF) Technology Roadmap 2017 aims to provide recommendations to Ministers of the CSLF member countries on technology developments that are required for carbon capture and storage (CCS)1 to fulfill the CSLF mission to facilitate the development and deployment of CCS technologies via collaborative efforts that address key technical, economic, and environmental obstacles.

With the release of this technology roadmap, the CSLF aspires to play an important role in reaching the targets set in the Paris Agreement by accelerating commercial deployment and to set key priorities for research, development, and demonstration (RD&D) of improved and cost-effective technologies for the separation and capture of carbon dioxide (CO_2); its transport; and its long-term safe storage or utilization.

Analysis by the International Energy Agency Greenhouse Gas R&D Programme (IEAGHG 2017a) shows that if sufficiently strong incentives for a technology are established, the rate of build-out historically observed in industry analogues (power sector, oil and gas exploration and production, pipeline transport of natural gas, and ship transport of liquefied natural gas) has been comparable to the rates needed to achieve the 2°C Scenario (2DS) for CCS.2 Reaching the beyond 2°C Scenario (B2DS) target will be significantly more challenging. Substantial investment in new CCS facilities from both the public and the private sectors is essential to achieve the required build-out rates over the coming decades. Governments need to establish market incentives and a stable policy commitment and to provide leadership to build public support for actions such as the following:

• A rapid increase of the demonstration of all the links in the CCS chain.

• Extensive support and efforts to build and operate new plants in power generation and industry.

• Facilitation of the exchange of data and experiences, particularly from existing large-scale plants with CCS.

• Support for continued and comprehensive RD&D.

• Facilitation of industrial clusters and CO_2 transport and storage hubs.

Priority Recommendations

Governments and industries must collaborate to ensure that CCS contributes its share to the Paris Agreement's aim to keep the global temperature increase from anthropogenic CO2 emissions to 2°C or below by implementing sufficient large-scale projects in the power and industry sectors to achieve the following:

• Long-term isolation from the atmosphere of at least 400 megatonnes (Mt) CO2 per year by 2025 (or permanent capture and storage of in total 1,800 Mt CO2).

• Long-term isolation from the atmosphere of at least 2,400 Mt CO2 per year by 2035 (or permanent capture and storage of in total 16,000 Mt CO2).

To this end, CSLF members recommend the following actions to the CSLF

Ministers:

• Promote the value of CCS in achieving domestic energy goals and global climate goals.

• Incentivize investments in CCS by developing and implementing policy frameworks.

• Facilitate innovative business models for CCS projects.

• Implement legal and regulatory frameworks for CCS.

• Facilitate CCS infrastructure development.

• Build trust and engage stakeholders through CCS public outreach and education.

• Leverage existing large-scale projects to promote knowledge-exchange opportunities.

• Drive costs down along the whole CCS chain through RD&D.

• Accelerate CCS in developing countries by funding storage appraisals and technology readiness assessments.

• Facilitate implementation of CO2 utilization.

CCS is a key technology to reduce CO2 emissions across various sectors of the economy while providing other societal benefits (energy security and access, air pollution reduction, grid stability, and jobs preservation and creation). Policy frameworks for CCS need to include equitable levels of consideration, recognition, and support for CCS on similar entry terms as other low-carbon technologies and reduce commercial risks.

To support the deployment of CCS, it is critical to facilitate innovative business models for CCS by creating an enabling market environment. Fit-for-purpose and comprehensive legal and regulatory frameworks for CCS are needed on a regional scale (e.g., the London Protocol to provide for offshore cross-border movement of CO2).

Strategic power and industrial CO2 capture hubs and clusters, with CO2 transportation and storage infrastructure, including early mapping matching sources to sinks and identification and characterization of potential storage sites, will also be needed.

CCS stakeholder engagement remains critical to implementation and is aimed at building trust, addressing misconceptions, and supporting educators and community proponents of CCS projects, while improving the quality of communication.

RD&D for novel and emerging technologies is required along the whole CCS chain, as shown by the Mission Innovation workshop on Carbon Capture, Utilization, and Storage held in September 2017. The same holds for knowledge sharing. These efforts should be targeted to provide the exchange of design, construction, and operational data, lessons learned, and best practices from existing large-scale projects.

The sharing of best practices continues to be of highest value and importance to driving CCS forward while bringing costs down. CO2 utilization can be facilitated by mapping opportunities; conducting technology readiness assessments; and resolving the main barriers for technologies, including life cycle assessments and CO2 and energy balances.

Key Findings

Based on reviews of several status reports on CCS and technical papers, as well as comments and input from international experts, the main findings of this Technology Roadmap 2017 are as follows:

• CCS has been proven to work and has been implemented in the power and industrial sectors.

• The coming years are critical for large-scale deployment of CCS; therefore, a sense of urgency must be built to drive action.

• Substantial, and perhaps unprecedented, investment in CCS and other low-carbon technologies is needed to achieve the targets of the Paris Agreement.

• The main barriers to implementation are inadequate government investment and policy support/incentives, challenging project economics, and uncertainties and risk that stifle private sector investment.

• Rapid deployment of CCS is critical in the industry and power sectors in both Organisation for Economic Co-operation and Development (OECD) and non-OECD countries, especially in those industries for which CCS is the most realistic path to decarbonization.

• Negative CO2 emissions can be achieved by using a combination of biomass and CCS.

• Costs and implementation risks can be reduced by developing industrial clusters and CO2 transport and storage hubs.

• Members of the CSLF consider it critical that public-private partnerships facilitate material and timely cost reductions and accelerated implementation of CCS.

More information

Read the full meeting report and documents:

www.cslforum.org

Artificial photosynthesis gets big boost from new catalyst

University of Toronto researchers have created a new catalyst that brings them one step closer to artificial photosynthesis — a system that would use renewable energy to convert carbon dioxide into stored chemical energy.

A new catalyst created by University of Toronto Engineering researchers brings them one step closer to artificial photosynthesis — a system that, just like plants, would use renewable energy to convert carbon dioxide (CO_2) into stored chemical energy. By both capturing carbon emissions and storing energy from solar or wind power, the invention provides a one-two punch in the fight against climate change.

"Carbon capture and renewable energy are two promising technologies, but there are problems," says Phil De Luna (MSE PhD Candidate), one of the lead authors of a paper published in Nature Chemistry. "Carbon capture technology is expensive, and solar and wind power are intermittent. You can use batteries to store energy, but a battery isn't going to power an airplane across the Atlantic or heat a home all winter: for that you need fuels."

De Luna and his co-lead authors Xueli Zheng and Bo Zhang — who conducted their work under the supervision of Professor Ted Sargent (ECE) — aim to address both challenges at once, and they are looking to nature for inspiration. They are designing an artificial system that mimics how plants and other photosynthetic organisms use sunlight to convert CO_2 and water into molecules that humans can later use for fuel.

As in plants, their system consists of two linked chemical reactions: one that splits H_2O into protons and oxygen gas, and another that converts CO_2 into carbon monoxide, or CO. (The CO can then be converted into hydrocarbon fuels through an established industrial process called Fischer-Tropsch synthesis.)

"Over the last couple of years, our team has developed very high-performing catalysts for both the first and the second reactions," says Zhang, who is one of the corresponding authors and is now a professor at Fudan University. "But while the second catalyst works under neutral conditions, the first catalyst requires high pH levels in order to be most active."

Phil De Luna (MSE PhD candidate) is one of the lead authors of a new paper published in Nature Chemistry that reports a low-cost, highly efficient catalyst for chemical conversion of water into oxygen. The catalyst is part of an artificial photosynthesis system being developed at U of T Engineering. (Photo: Tyler Irving)

That means that when the two are combined, the overall process is not as efficient as it could be, as energy is lost when moving charged particles between the two parts of the system.

The team has now overcome this problem by developing a new catalyst for the first reaction — the one that splits water into protons and oxygen gas. Unlike the previous catalyst, this one works at neutral pH, and under those conditions it performs better than any other catalyst previously reported.

"It has a low overpotential, which means less electrical energy is needed to drive the reaction forward," says Zheng, (ECE PhD 1T7) who is now a postdoctoral scholar at Stanford University. "On top of that, having a catalyst that can work at the same neutral pH as the CO_2 conversion reaction reduces the overall potential of the cell."

In the paper, the team reports the overall electrical-to-chemical power conversion efficiency of the system at 64 per cent. According to De Luna, this is the highest value ever achieved for such a system, including their previous one, which only reached 54 per cent.

The new catalyst is made of nickel, iron, cobalt and phosphorus, all elements that are low-cost and pose few safety hazards. It can be synthesized at room temperature using relatively inexpensive equipment, and the team showed that it remained stable as long as they tested it, a total of 100 hours.

Armed with their improved catalyst, the Sargent lab is now working to build their artificial photosynthesis system at pilot scale. The goal is to capture CO2 from flue gas — for example, from a natural gas-burning power plant — and use the catalytic system to efficiently convert it into liquid fuels.

"We have to determine the right operating conditions: flow rate, concentration of electrolyte, electrical potential," says De Luna. "From this point on, it's all engineering."

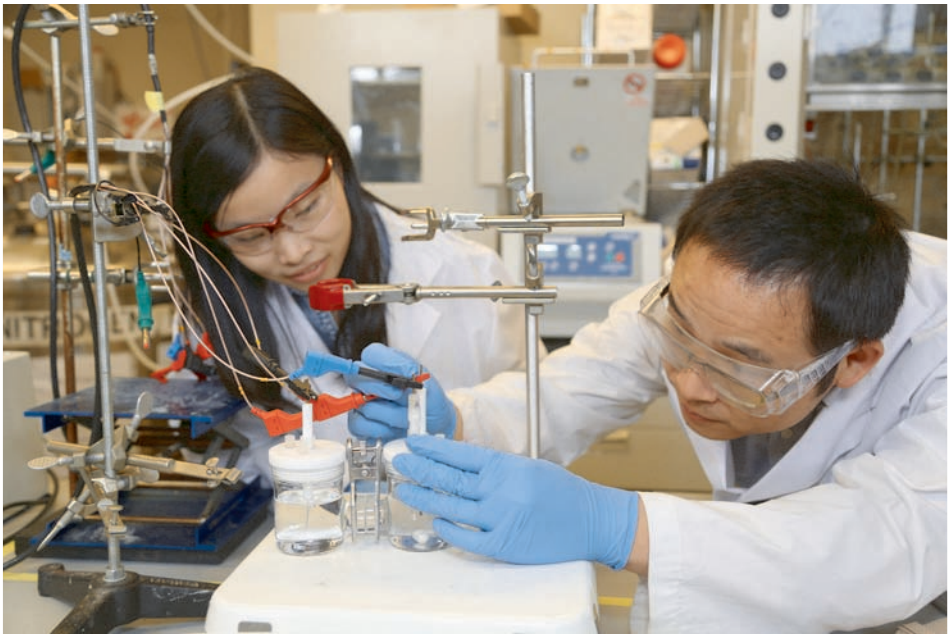
The team and their invention are semi-finalists in the NRG COSIA Carbon XPRIZE, a $20 million challenge to "develop breakthrough technologies that will convert CO2 emissions from power plants and industrial facilities into valuable products."

The project was the result of an international and multidisciplinary collaboration. The Canadian Light Source in Saskatchewan provided the high-energy x-rays used to probe the electronic properties of the catalyst. The Molecular Foundry at the U.S. Department of Energy's Lawrence Berkeley National Laboratory did theoretical modelling work.

Financial and in-kind support were provided by the Natural Sciences and Engineering Research Council, the Canada Foundation for Innovation, Tianjin University, Fudan University and the Beijing Light Source.

As for what has kept him motivated throughout the project, De Luna points to the opportunity to make an impact on some of society's biggest environmental challenges.

"Seeing the rapid advancement within the field has been extremely exciting," he says. "At every weekly or monthly conference that we have within our lab, people are smashing records left and right. There is still a lot of room to grow, but I genuinely enjoy the research, and carbon emissions are such a big deal that any improvement feels like a real accomplishment."



Researchers Xueli Zheng, left, and Bo Zhang test a previous catalyst for the artificial photosynthesis system. The new catalyst works at lower pH, leading to an improvement in the overall efficiency of the system. (Photo: Marit Mitchell)

More information

www.utoronto.ca

Making carbon nanotubes and hydrogen from methane

www.socalgas.com

Southern California Gas Co. (SoCalGas) is partnering with a development team to advance a new process that converts natural gas to hydrogen, carbon fiber, and carbon nanotubes.

The low-emission process, selected for funding by the U.S. Department of Energy's (DOE) Fuel Cell Technologies Office (FCTO) within the Office of Energy Efficiency and Renewable Energy (EERE), will create both hydrogen that can be used in fuel cell vehicles and industrial processes, as well as carbon fiber used in applications from medical devices and aerospace structures to building products.

The goal of the partnership, led by C4-MCP, LLC (C4), a Santa Monica-based technology start-up, is to offset the hydrogen production expense with the sales of the carbon fiber and carbon nanotubes, reducing the hydrogen's net cost to under $2 per kilogram, thus helping make hydrogen fueled cars and trucks cost-competitive with conventional gasoline and diesel vehicles. In addition, this technology will virtually eliminate CO2 emissions from the methane-to-hydrogen process. These efforts support FCTO's focus on early stage research and development to enable innovations to be demonstrated and to help guide further early stage research strategy.

"This technology takes methane, turns it into a zero-emission automotive fuel—hydrogen—then uses the carbon captured in the process to make the strongest possible materials to be used in high-tech manufacturing," said Yuri Freedman, SoCalGas senior director of market development. "Further advances in development of this technology will bring about a unique and potentially revolutionary combination of environmental, manufacturing, and economic benefits."

While carbon fiber and its uses are well-known, carbon nanotubes (CNTs) are viewed as a big leap forward in materials science and engineering because they have tensile strength and stiffness many times that of carbon fiber. The global CNT market was estimated at approximately $3.5 billion in 2016 and is expected to increase to $8.7 billion by 2022 with robust growth rates over 17 percent annually, according to experts at SoCalGas.

The partnership will develop an advanced methane reforming process based on a new catalyst used to make CNTs, recently discovered by WVU Statler Chair Engineering Professor John Hu. The new catalyst system promotes "base growth" carbon nanotube formation rather than "tip growth," the current technology. Base growth formation enables the catalyst to regenerate while also creating a highly pure and crystalline carbon product. In addition, the reaction conditions can be optimized to tune the diameter and length of the CNTs produced.

Ohio State chemical looping for CO2 negative electricity

Engineers at The Ohio State University are developing technologies that have the potential to economically convert fossil fuels and biomass into useful products including electricity without emitting carbon dioxide to the atmosphere.

In the first of two papers published in the journal Energy & Environmental Science, the engineers report that they've devised a process that transforms shale gas into products such as methanol and gasoline—all while consuming carbon dioxide. This process can also be applied to coal and biomass to produce useful products.

Under certain conditions, the technology consumes all the carbon dioxide it produces plus additional carbon dioxide from an outside source.

In the second paper, they report that they've found a way to greatly extend the lifetime of the particles that enable the chemical reaction to transform coal or other fuels to electricity and useful products over a length of time that is useful for commercial operation.

Finally, the same team has discovered and patented a way with the potential to lower the capital costs in producing a fuel gas called synthesis gas, or "syngas," by about 50 percent over the traditional technology.

L.S. Fan, Distinguished University Professor in Chemical and Biomolecular Engineering at The Ohio State University, holds samples of materials developed in his laboratory that enable clean energy technologies. Photo by Jo McCulty, courtesy of The Ohio State University.

The technology, known as chemical looping, uses metal oxide particles in high-pressure reactors to "burn" fossil fuels and biomass without the presence of oxygen in the air. The metal oxide provides the oxygen for the reaction.

Chemical looping is capable of acting as a stopgap technology that can provide clean electricity until renewable energies such as solar and wind become both widely available and affordable, the engineers said.

"Renewables are the future," said Liang-Shih Fan, Distinguished University Professor in Chemical and Biomolecular Engineering, who leads the effort. "We need a bridge that allows us to create clean energy until we get there—something affordable we can use for the next 30 years or more, while wind and solar power become the prevailing technologies."

Five years ago, Fan and his research team demonstrated a technology called coal-direct chemical looping (CDCL) combustion, in which they were able to release energy from coal while capturing more than 99 percent of the resulting carbon dioxide, preventing its emission to the environment. The key advance of CDCL came in the form of iron oxide particles which supply the oxygen for chemical combustion in a moving bed reactor. After combustion, the particles take back the oxygen from air, and the cycle begins again.

The challenge then, as now, was how to keep the particles from wearing out, said Andrew Tong, research assistant professor of chemical and biomolecular engineering at Ohio State.

While five years ago the particles for CDCL lasted through 100 cycles for more than eight days of continuous operation, the engineers have since developed a new formulation that lasts for more than 3,000 cycles, or more than eight months of continuous use in laboratory tests. A similar formulation has also been tested at sub-pilot and pilot plants.

"The particle itself is a vessel, and it's carrying the oxygen back and forth in this process, and it eventually falls apart. Like a truck transporting goods on a highway, eventually it's going to undergo some wear and tear. And we're saying we devised a particle that can make the trip 3,000 times in the lab and still maintain its integrity," Tong said.

This is the longest lifetime ever reported for the oxygen carrier, he added. The next step is to test the carrier in an integrated coal-fired chemical looping process.

Another advancement involves the engineers' development of chemical looping for production of syngas, which in turn provides the building blocks for a host of other useful products including ammonia, plastics or even carbon fibers.

This is where the technology really gets interesting: It provides a potential industrial use for carbon dioxide as a raw material for producing useful, everyday products.

Today, when carbon dioxide is scrubbed from power plant exhaust, it is intended to be buried to keep it from entering the atmosphere as a greenhouse gas. In this new scenario, some of the scrubbed carbon dioxide wouldn't need to be buried; it could be converted into useful products.

Taken together, Fan said, these advancements bring Ohio State's chemical looping technology many steps closer to commercialization.

He calls the most recent advances "significant and exciting," and they've been a long time coming. True innovations in science are uncommon, and when they do happen, they're not sudden. They're usually the result of decades of concerted effort—or, in Fan's case, the result of 40 years of research at Ohio State. Throughout some of that time, his work has been supported by the U.S. Department of Energy and the Ohio Development Services Agency.

"This is my life's work," Fan said.

Andrew Tong, research assistant professor of chemical and biomolecular engineering at The Ohio State University, examines equipment in the Clean Energy Research Laboratory. Photo by Jo McCulty, courtesy of The Ohio State University.

His co-authors on the first paper include postdoctoral researcher Mandar Kathe; undergraduate researchers Abbey Empfield, Peter Sandvik, Charles Fryer, and Elena Blair; and doctoral student Yitao Zhang. Co-authors on the second paper include doctoral student Cheng Chung, postdoctoral researcher Lang Qin, and master's student Vedant Shah. Collaborators on the pressure adjustment assembly work include Tong, Kathe and senior research associate Dawei Wang.

New materials under development at The Ohio State University, including a patented iron oxide particle (left), are enabling cleaner fossil fuel technologies. Photo by Jo McCulty, courtesy of The Ohio State University

The university would like to partner with industry to further develop the technology.

The Linde Group, a provider of hydrogen and synthesis gas supply and plants, has already begun collaborating with the team. Andreas Rupieper, the head of Linde Group R&D at Technology & Innovation said that the ability to capture carbon dioxide in hydrogen production plants and use it downstream to make products at a competitive cost "could bridge the transition towards a decarbonized hydrogen production future." He added that "Linde considers Ohio State's chemical looping platform technology for hydrogen production to be a potential alternative technology for its new-built plants".

The Babcock & Wilcox Company (B&W), which produces clean energy technologies for power markets, has been collaborating with Ohio State for the past 10 years on the development of the CDCL technology – an advanced oxy-combustion technology for electricity production from coal with nearly zero carbon emissions. David Kraft,

Technical Fellow at B&W, stated "The CDCL process is the most advanced and cost-effective approach to carbon capture we have reviewed to date and are committed to supporting its commercial viability through large-scale pilot plant design and feasibility studies. With the continued success of collaborative development program with Ohio State, B&W believes CDCL has potential to transform the power and petrochemical industries."

More information

www.osu.edu

Capture and utilisation news

MIT develops method to convert carbon dioxide into useful compounds

www.mit.edu

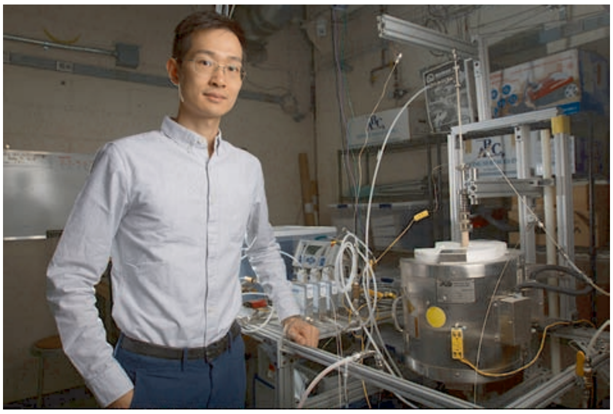
MIT researchers have developed a new system that could potentially be used for converting power plant emissions of carbon dioxide into useful fuels.

The new membrane-based system was developed by MIT postdoc Xiao-Yu Wu and Ahmed Ghoniem, the Ronald C. Crane Professor of Mechanical Engineering, and is described in a paper in the journal ChemSusChem. The membrane, made of a compound of lanthanum, calcium, and iron oxide, allows oxygen from a stream of carbon dioxide to migrate through to the other side, leaving carbon monoxide behind. Other compounds, known as mixed ionic electronic conductors, are also under consideration in their lab for use in multiple applications including oxygen and hydrogen production.

Carbon monoxide produced during this process can be used as a fuel by itself or combined with hydrogen and/or water to make many other liquid hydrocarbon fuels as well as chemicals including methanol (used as an automotive fuel), syngas, and so on. Ghoniem's lab is exploring some of these options. This process could become part of the suite of technologies known as carbon capture, utilization, and storage, or CCUS, which if applied to electicity production could reduce the impact of fossil fuel use on global warming.

The membrane, with a structure known as perovskite, is "100 percent selective for oxygen," allowing only those atoms to pass, Wu explains. The separation is driven by temperatures of up to 990 degrees Celsius, and the key to making the process work is to keep the oxygen that separates from carbon dioxide flowing through the membrane until it reaches the other side. This could be done by creating a vacuum on side of the membrane opposite the carbon dioxide stream, but that would require a lot of energy to maintain.

In place of a vacuum, the researchers use a stream of fuel such as hydrogen or methane. These materials are so readily oxidized that they will actually draw the oxygen atoms through the membrane without requiring a pressure difference. The membrane also prevents the oxygen from migrating back and recombining with the carbon monoxide, to form carbon dioxide all over again. Ultimately, and depending on the application, a combination of some vaccum and some fuel can be used to reduce the energy required to drive the process and produce a useful product.



Xiao-Yu Wu pictured with the reactor his team used for the research. MIT researchers have developed a new system that could potentially be used for converting power plant emissions of carbon dioxide into useful fuels. The method may not only cut greenhouse emissions; it could also produce another potential revenue stream to help defray its costs. (Image: Tony Pulsone)

The energy input needed to keep the process going, Wu says, is heat, which could be provided by solar energy or by waste heat, some of which could come from the power plant itself and some from other sources. Essentially, the process makes it possible to store that heat in chemical form, for use whenever it's needed. Chemical energy storage has very high energy density — the amount of energy stored for a given weight of material — as compared to many other storage forms.

At this point, Wu says, he and Ghoniem have demonstrated that the process works. Ongoing research is examining how to increase the oxygen flow rates across the membrane, perhaps by changing the material used to build the membrane, changing the geometry of the surfaces, or adding catalyst materials on the surfaces.

The researchers are also working on integrating the membrane into working reactors and coupling the reactor with the fuel production system. They are examining how this method could be scaled up and how it compares to other approaches to capturing and converting carbon dioxide emissions, in terms of both costs and effects on overall power plant operations.

In a natural gas power plant that Ghoniem's group and others have worked on previously, Wu says the incoming natural gas could be split into two streams, one that would be burned to generate electricity while producing a pure stream of carbon dioxide, while the other stream would go to the fuel side of the new membrane system, providing the oxygen-reacting fuel source. That stream would produce a second output from the plant, a mixture of hydrogen and carbon monoxide known as syngas, which is a widely used industrial fuel and feedstock. The syngas can also be added to the existing natural gas distribution network.

The method may thus not only cut greenhouse emissions; it could also produce another potential revenue stream to help defray its costs.

The process can work with any level of carbon dioxide concentration, Wu says — they have tested it all the way from 2 percent to 99 percent — but the higher the concentration, the more efficient the process is. So, it is well-suited to the concentrated output stream from conventional fossil-fuel-burning power plants or those designed for carbon capture such as oxy-combustion plants.

"It is important to use carbon dioxide to produce carbon monoxide for the conversion of sustainable thermal energies to chemical energy," says Xuefeng Zhu, a professor of chemical physics at the Chinese Academy of Sciences, in Dalian, China, who was not involved in this work. "Using an oxygen-permeable membrane can significantly reduce the reaction temperature, from 1,500 C to less than 1,000 C, indicating a great energy saving compared to the traditional carbon dioxide decomposition process," he says. "I think their work is important to the field of sustainable energy and membrane processes."

The research was funded by Shell Oil and the King Abdullah University of Science and Technology.

New technique could make captured carbon more valuable

www.inl.gov

Scientists at the U.S. Department of Energy's Idaho National Laboratory have developed an efficient process for turning captured carbon dioxide into syngas, a mixture of H2 and CO that can be used to make fuels and chemicals.

The team has published its results in Green Chemistry, a publication of the Royal Society of Chemistry .

Traditional approaches for reusing the carbon from CO2 involve a reduction step that requires high temperatures and pressures. At lower temperatures, the CO2 doesn't stay dissolved in water long enough to be useful. The process developed at INL addresses this challenge by using specialized liquid materials that make the CO2 more soluble and allow the carbon capture medium to be directly introduced into a cell for electrochemical conversion to syngas.

"For the first time it was demonstrated that syngas can be directly produced from captured CO2 - eliminating the requirement of downstream separations," the researchers wrote in the Green Chemistry paper.

The newly described process uses switchable polarity solvents (SPS), liquid materials that can shift polarity upon being exposed to a chemical agent. This property makes it possible to control what molecules will dissolve in the solvent.

In an electrochemical cell, water oxidation occurs on the anode side, releasing O2 gas and hydrogen ions that then migrate through a membrane to the cathode side. There, the hydrogen ions react with bicarbonate (HCO3-, the form in which CO2 is captured in the SPS), allowing the release of CO2 for electrochemical reduction and formation of syngas. Upon the release of CO2, the SPS switches polarity back to a water-insoluble form, allowing for the recovery and reutilization of the carbon capture media.

Luis Diaz Aldana, principal investigator on the experiment, and Tedd Lister, one of the researchers, conduct electrochemical research at INL. In 2015, while having lunch with colleagues Eric Dufek and Aaron Wilson, they hit on the idea of using switchable polarity solvents to turn CO2 into syngas.

The team received Laboratory Directed Research and Development funds in 2017. As promising as the idea was, in the first experiments, too much hydrogen and not enough syngas was being produced. The results improved when the team introduced a supporting electrolyte to increase the ionic conductivity. Adding potassium sulfate increased electrolyte conductivity by 47 percent, which allowed the efficient production of syngas.

When syngas can be produced from captured CO2 at significant current densities, it boosts the process chances for industrial application. Unlike other processes that require high temperatures and high pressures, the SPS-based process showed best results at 25 degrees C and 40 psi.

INL's team has filed a provisional patent and is discussing the approach with a Boston area company involved in electrochemical technology research and development, Lister said.

Surrey University develops 'supercatalyst' to recycle carbon dioxide and methane

www.surrey.ac.uk

The University of Surrey has developed a new and cost-effective catalyst to recycle two of the main causes behind climate change - carbon dioxide (CO2) and methane (CH4).

In a study published by the Applied Catalysis B: Environmental, scientists have described how they created an advanced nickel-based catalyst strengthened with tin and ceria, and used it to transform CO2 and CH4 into a synthesis gas that can be used to produce fuels and a range of valuable chemicals.

The project is part of the Engineering and Physical Sciences Research Council's Global Research Project, which is looking into ways to lessen the impact of global warming in Latin America. The study has led the University of Surrey to file a patent for a family of new "supercatalysts" for chemical CO2 recycling.

According to the Global Carbon Project, global CO2 emissions are set to rise in 2017 for the first time in four years - with carbon output growing on average three per cent every year since 2006.

While carbon capture technology is common, it can be expensive and, in most cases, requires extreme and precise conditions for the process to be successful. It is hoped the new catalyst will help make the technology more widely available across industry, and both easier and cheaper for it to be extracted from the atmosphere.

A biological solution to carbon capture and recycling?

www.lifesci.dundee.ac.uk

Scientists at the University of Dundee have discovered that E. coli bacteria could hold the key to an efficient method of capturing and storing or recycling carbon dioxide.

Professor Frank Sargent and colleagues at the University of Dundee's School of Life Sciences, working with local industry partners Sasol UK and Ingenza Ltd, have developed a process that enables the E. coli bacterium to act as a very efficient carbon capture device.

Professor Sargent said, "Reducing carbon dioxide emissions will require a basket of different solutions and nature offers some exciting options. Microscopic, single-celled bacteria are used to living in extreme environments and often perform chemical reactions that plants and animals cannot do."

"For example, the E. coli bacterium can grow in the complete absence of oxygen. When it does this it makes a special metal-containing enzyme, called 'FHL', which can interconvert gaseous carbon dioxide with liquid formic acid. This could provide an opportunity to capture carbon dioxide into a manageable product that is easily stored, controlled or even used to make other things. The trouble is, the normal conversion process is slow and sometime unreliable."

"What we have done is develop a process that enables the E. coli bacterium to operate as a very efficient biological carbon capture device. When the bacteria containing the FHL enzyme are placed under pressurised carbon dioxide and hydrogen gas mixtures – up to 10 atmospheres of pressure – then 100 per cent conversion of the carbon dioxide to formic acid is observed. The reaction happens quickly, over a few hours, and at ambient temperatures."

"This could be an important breakthrough in biotechnology. It should be possible to optimise the system still further and finally develop a `microbial cell factory' that could be used to mop up carbon dioxide from many different types of industry.

Exa and BP – get relative permeability from a digital rock sample

Exa Corporation has developed software together with BP to model flows of multiple fluids through a digital image of a physical rock sample, and so find the relative permeability, a critical factor in understanding the reservoir.
By Karl Jeffery

Exa Corporation, a company based in Massachusetts, USA, has developed a way to simulate fluid flow through a digital image of a physical rock sample without losing any resolution, working together with BP. The technology is provided as an online software product called DigitalROCK.

The simulation solution was co-developed with BP, during a 3 year technology collaboration agreement.

It can be used to understand relative permeability – how multiple fluids flow through a reservoir, and the forces they will make on each other.

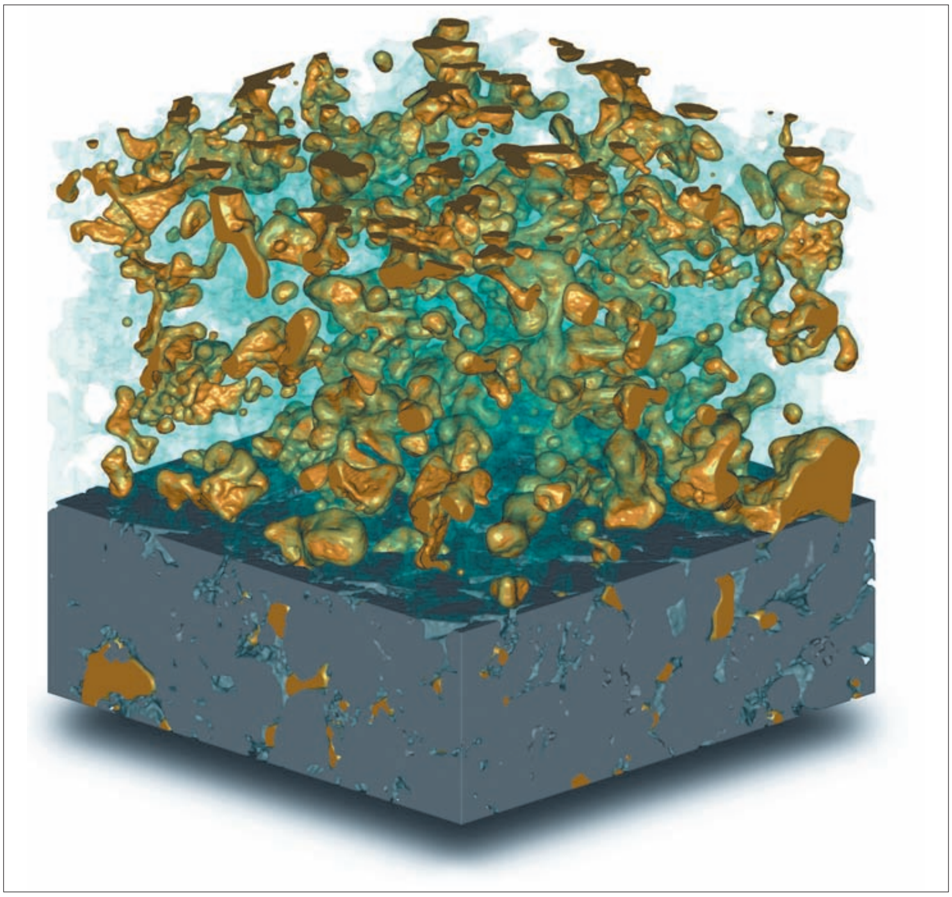
Exa claims that this is the first predictive computational solver for relative permeability for oil and gas.

Relative permeability is the resistance to flow for a mixture of fluids – for example a certain reservoir might allow water to flow through much more easily than oil. It is different to absolute permeability, which is the reservoir's overall resistance to flow.

The relative permeability can be used to understand what ultimate recovery can be achieved from the reservoir (a function of how much oil will be left behind in the pore spaces and never flow to a well). It can enable an understanding of how this can be changed with an enhanced oil recovery technique or water flood.

The basis of the study is a 3D CT (computerised tomography) scan of a small piece of core or drill cutting. Clients can take a scan image themselves, and upload it to Exa's online software, to run a simulation.

Exa is a simulation software company, specialising in computational fluid dynamics. It also serves the automotive, aerospace and aviation industries.



Exa DigitalROCK provides a virtual core analysis lab for determining critical flow-related rock properties. It offers a fast, cost-effective alternative to laboratory tests by dramatically accelerating the process of physically testing core samples. (Image: Exa Corporation)

Exa provides purely software, provided over the cloud. You can upload a 3D CT image, and start running flow analysis, getting results "in a relatively short time."

BP agreement

Exa has been developing its flow simulation technology for a "couple of decades", and realised it might be helpful when used together with pore scale imaging.

The company met BP in 2014, who were trying to solve the problem of relative permeability simulation. BP had done digital rock scanning, but not simulating multiphase flow.

In May 2017, Exa announced it had signed a multiyear "commercial agreement" with BP to provide its DigitalROCK relative permeability software.

BP said that the capability "will help engineering teams to make more informed decisions on wells, production facilities and resource progression, including enhanced oil recovery."

"The ability to generate reliable relative permeability information directly from digital scans on a much faster time-scale than laboratory testing, and to gain insight into the underlying pore-scale dynamics, provides substantial business value during appraisal, development, and management of our reservoirs," said Dr. Joanne Fredrich, upstream technology senior advisor at BP, in a press release quote.

"We plan to deploy this technology across our global portfolio. After a three-year program of cooperative development and testing, our extensive validation studies are drawing to a close."

BP uses the software as part of its "Digital Rocks" program, and the technology has been used across BP's global portfolio including fields in Angola, the Gulf of Mexico, the North Sea, Egypt, Azerbaijan, the Middle East, India, and Trinidad and Tobago.

BP's Digital Rocks team includes experts in 3D imaging, fluid mechanics, numerical modelling, computational physics, high performance computing, rock physics and reservoir engineering. The technology is implemented in its Centre for High Performance Computing (CHPC) in Houston.

Replacing physical cores

Until now, the only way to understand how different fluids will flow through a rock sample is to do a physical test in a laboratory, with a piece of core sample and test reservoir fluids, under similar pressure and temperature to the reservoir conditions.

But, aside from the expense of setting this up, means that you can only test a single core sample once, and so it is hard to make comparisons. You can't find out how the results might be different with for example a higher pressure water injection. Also lab results can take a year or even more.

Evolution of technology

Oil companies have been scanning rock samples in tomography scans and using the scan to model flow for about a decade now. The difference with Exa's technology is that it does not simplify the rock geometry at all for the modelling.

Other companies have made a model of pores from the scanned image, which can be good for analysing porosity, or single phase flow, but does not necessarily tell you how multiphase flow will travel through the rock, says David Freed, vice president oil and gas at Exa Corporation.

Flow in real oilfields is nearly always multiphase, Dr. Freed says, with oil and gas, oil and water, water and gas, or all three. Having just one fluid is "extremely rare" (except if it is water).

Reservoir rocks nearly always begin filled with water filling their pore spaces, and hydrocarbons percolate in there over time and push the water out.

With Exa's software, the simulation is made without simplifications to make the computer model easier to compute. Its simulation technique uses the full geometry of the pore space.

In the simulation you can see oil and water moving within the pore space, and see how pockets of oil are getting trapped. There is a short video on exa.com website illustrating this.

The flow simulation takes into account the conditions which the reservoir is under, and how the results will change for different conditions.

Using the data

The data about relative permeability can be used as part of reservoir models, used for example to make decisions about where to place wells, and design enhanced oil recovery techniques.

Unless you understand the way different fluids behave then any predictions made by the simulators will not be very accurate. This includes simulations of how injection water will push oil out of the pores and increase recovery.

The data can be used to work out the end point – how much oil you will actually be able to produce from the reservoir, or in other words how much oil will stay in the pores at the point when no more oil is flowing to the oil wells.

The recovery factor of reservoirs varies greatly, from 20 per cent to 60 per cent, and this is the major factor in the return the company gets from the investment in building the oilfield.

The reason not all of the oil is produced is because some of it is left behind in the pores, trapped by capillary forces.

The data is also useful if the company is planning any water or CO2 flooding.

The water relative permeability also tells you how much water is being produced, something which operators also care about, because it is expensive producing and handling that water – and it also occupies topsides capacity.

And it is also important to be able to predict water production, so you can make sure your topsides capacity is able to handle it.

Oil companies are experimenting with surfactants (soaps) in injected water, which reduce the surface tension of the fluid mixture – so changing the flow conditions. With Exa's technology, you can get a sense of how a surfactant will change the hydrocarbon recovery, before you do it.

Carbon capture

The technology could also be useful when planning CO2 enhanced gas recovery / enhanced oil recovery projects, such as using CO2 in coal seam gas fields.

CO2 has been observed to reduce the viscosity of oil, and reduce the amount of gas which stays in coal seam pores, thus increasing oil and gas production.

But the precise mechanics are not very well understood, and detailed predictions of what CO2 flows will lead to what improved oil and gas flows are hard to make. This means there are no hard numbers available to justify making an investment decision about a carbon capture and storage project.

By getting an understanding of relative permeability using software like Exa's, it would be possible to get a much better idea of the return of investment in such a project, and whether it might make sense to do a pilot project. It would also help compare different options.

More information

www.exa.com

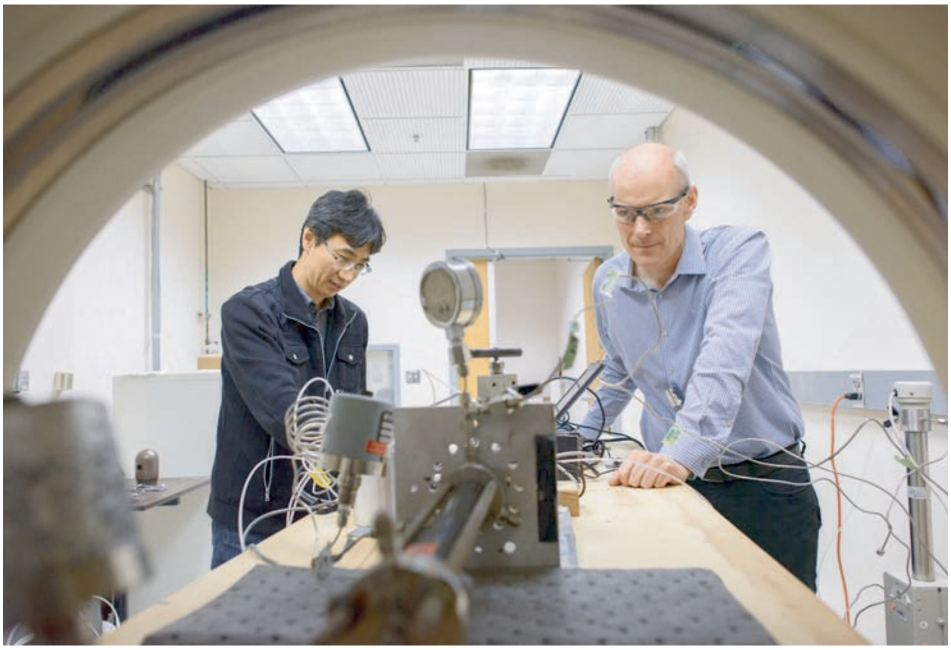
Stanford studies geological CO2 storage with CT scanners

Stanford researchers are using CT scanners to help understand how CO2 behaves in geological subsurface storage projects.

Of the approximately two dozen medical CT scanners scattered throughout Stanford's main campus and medical centers, two can be found nestled in basement labs of the Green Earth Sciences Buildings.

The scanner duo is being put to some decidedly off-label uses in research led by Anthony Kovscek, a professor of energy resources engineering at Stanford's School of Earth, Energy & Environmental Sciences (Stanford Earth). The machines in this case have helped scientists extract oil and gas more efficiently, and are now revealing ways of storing carbon dioxide (CO2) deep underground while the world continues to rely on fossil fuels for energy and transportation.

The motorized tables that would normally slide patients in and out of the scanners' openings instead support machines made from a daunting array of connected pressure vessels, nozzles and gauges shrouded beneath wires and tubing. The larger of the two scanners is about the length of a person and looks like something devised by a mad scientist to power a time-traveling DeLorean. "I'll still sometimes say 'Whoa' when I see it," said Muhammad Almajid, a graduate student in Kovscek's lab.



Research scientist Tae Wook Kim, left, and professor Tony Kovscek check the status of an experiment in the CT scanner. (Image credit: L.A. Cicero)

The ad hoc devices, which Almajid and his colleagues painstakingly craft and assemble by hand, are designed to force pressurized oil, water or gas through slim cylinders of seemingly solid rock, which the scanners then analyze with X-rays.

"We try to visualize things that people say you can't visualize," said Kovscek, who is the Keleen and Carlton Beal Professor of Petroleum Engineering at Stanford. "It's happened more than once, where someone will say, 'Well, you just can't do it.' And I point to our results and say, 'Well, I beg to differ.'"

The lab experiments are intended to recreate, in miniature, the movement of various substances through vast rock formations and to provide real-world validation of computer simulations of the same processes. This type of experimentation and simulation has helped the United States move toward energy security by enabling the nation to tap vast reserves of previously inaccessible oil and natural gas, such as shale oil.

But what's learned from that mass of tubes and gauges could also help mitigate the effects of burning 100 million barrels of oil per day, which is expected to continue for at least 50 years while the world transitions to renewable energy sources. Results like the ones from Kovscek's lab are now guiding new ways of sequestering the powerful greenhouse gas carbon dioxide, which is released from burning fossil fuels, deep within rocks, for eons, while avoiding leaks and other negative consequences – a strategy many experts say is going to be necessary in order to avoid the hazards of climate change.

"Greater efficiency in oil recovery and conversion of the energy system to renewables has to happen. But there is a multi-decade period where we really have to make sure that CO2 emissions are under control while hydrocarbons are still being consumed at high rates," said Hamdi Tchelepi, a professor of energy resources engineering who frequently collaborates with Kovscek. "The only way to achieve that is through a serious, large-scale deployment of carbon sequestration. It's not optional. In the eyes of the scientific community, this has to happen."

Trapping carbon underground

Some of the strategies for efficiently extracting oil and natural gas from reservoirs that came out of work like Kovscek's are also a first step toward carbon sequestration.

Especially relevant is a practice called enhanced oil recovery (EOR) by gas injection, which involves pumping pressurized gases into existing oil fields to displace or reduce the viscosity of crude oil, making it easier to extract. Even the best performing fields still leave about 50 percent of oil in the ground, Kovscek said. For unconventional resources such as shale rocks, which are even more difficult to extract oil from, the recovery rate can be as low as 5 percent.

"That means if we don't do anything further on a well after the initial recovery, we're going to leave as much as 95 percent of the resource in the ground," Kovscek said. "That's a huge waste of all the energy that it took to drill the well and the water injection and hydraulic fracturing that may have been required to operate it."

CO_2, it turns out, mixes very well with crude oil, making it, in petroleum engineering parlance, an excellent "EOR fluid." Thus, for decades now, and for its own purposes, the fossil fuel industry has been refining the process of injecting huge amounts of CO_2 deep underground.

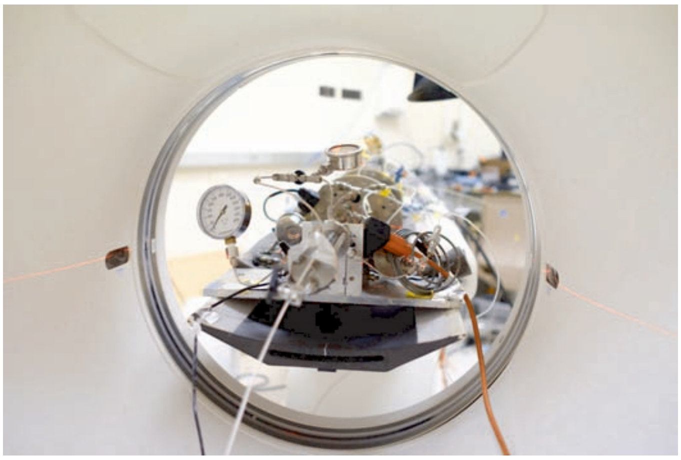
The challenge for people like Kovscek and his colleagues is keeping that gas imprisoned underground and out of the atmosphere for long periods of time without unanticipated consequences.

"Oil companies are mostly interested in what's called the active injection period because their goal is to get a return on investment within one or two decades," Tchelepi said. "For sequestration, you need to inject CO_2 for a couple of decades and then turn the valves off. And the physics of what happens after you stop injecting is more complicated than the physics used for oil recovery. You have to truly go a step beyond, because the time scales are so long."

Understanding the dangers

A major focus of Tchelepi's research is using 4-D computer simulations to predict how sequestered CO_2 will interact with faults deep within the Earth across centuries and eons. "In some cases, we've modeled 3,000 to 4,000 years into the future," Tchelepi said. "The ideal target for sequestration would be a large, reasonably homogenous rock basin that doesn't have any fractures. But nature isn't always so kind to us."

The dangers associated with CO_2 interacting wrongfully with faults are myriad. One risk is that the highly pressurized gas might nudge an already stressed fault toward its breaking point, generating earthquakes. Another risk that an existing crack is widened by the CO_2, creating a pathway for other, more noxious gases to seep to the surface or pollute aquifers used for drinking and agriculture. "Carbon dioxide and water is Pellegrino [sparkling water]," Tchelepi said, "but it's not pure Pellegrino, because CO_2 usually contains harmful impurities that get generated when coal is burned but that aren't fully removed before injection."



CT scanner in the lab of Anthony Kovscek conducts experiments meant to mimic the flow of liquids and gases deep underground. (Image credit: Ker Than)

Trying to minimize the risk of CO_2 leakage is a focus of Lou Durlofsky's research. Durlofsky, who is a professor of energy resources engineering, is adapting techniques from oil and gas applications to simulate the impacts of placing CO_2 injection wells in different locations and varying the rates at which injection occurs. With powerful computer simulations, Durlofsky's team can play virtual "what-if" games that allow it to determine well locations and injection sequences that nudge sequestered CO_2 toward a desired fate.

The best-case scenario for trapped CO_2 is for it to react with rock and form long-lasting minerals, but this process requires very long timescales to occur. However, there are two other favorable outcomes, which can happen much faster: dissolution, whereby the CO_2 gets dissolved in salt water, and residual trapping, which is when CO_2 gets broken up into very small bubbles that resist leakage.

"Because the CO_2 is now in the form of discrete blobs, it can't flow as easily and is effectively trapped in place," explained Durlofsky, who is the Otto N. Miller Professor in Earth Sciences at Stanford. "By varying where and how CO_2 gets injected in the formation, we can increase the likelihood that one or the other of these outcomes will occur."

'Green oil'

Despite the risks of leakage, Tchelepi said the results from Kovscek's scanner experiments and his own team's computer simulations indicate that safe, long-term carbon sequestration is within reach — and he thinks the technique should be deployed now, even though it's still in its infancy. "It's far from being perfected, but we know more than enough, in my opinion, to start using it," Tchelepi said. "Clearly, there will be issues and problems, but the only way to deal with them is to put them under the control of science and engineering, to monitor them and to spend the resources to learn from the mistakes. The risk of waiting for perfection is too big. We know enough."

One idea that Kovscek and Tchelepi's labs are exploring is combining EOR and carbon sequestration to create what they refer to as "green oil." "If you can take all of the CO_2 that is generated from burning the oil or natural gas that's extracted in the future from a reservoir, inject it back into the reservoir and store it securely, you would have net-zero carbon emissions," Kovscek said. "Sequestration is expensive. If we can recover something valuable in the process, it can be used to pay for the sequestration."

While some might see a contradiction in helping maximize the extraction of oil and natural gas, on the one hand, and working to sequester the CO_2 created from the burning of those same fuels on the other, Tchelepi views the two goals as complementary.

"You have to be realistic that we will use 100 million barrels of oil a day for the next 50 years," he said. "Should we do that in a messy, uncontrolled way? Or should we do it with the best possible engineering, maximize the recovery and optimize it by coupling it with sequestration? I'm working on the second option."

More information

energy.stanford.edu

Making progress in monitoring CO2 storage using chemical tracers

The benefits of knowledge sharing within the international carbon capture and storage (CCS) community have been highlighted by a new research paper, which focuses on the use of chemical tracers in CO2 leakage monitoring for offshore CCS projects worldwide.

The paper by scientists from the Scottish Carbon Capture & Storage (SCCS) partnership looks at the constraints and cost implications of using chemical tracers. The research followed consultation with the wider CCS community for their thoughts on research priorities for monitoring offshore stores. Measuring CO2 leakage to the seabed was an area identified as requiring further work.

Postdoctoral researcher, Dr Anita Flohr, from the University of Southampton, who is working on STEMM-CCS, said, "If a tracer qualifies for commercial-scale monitoring programmes of CO2 storage, it is not only a matter of its physical and chemical properties but also a matter of the logistics, technology and costs behind the sampling, processing and analysis. To me, the significance of this review is that it summarises the key findings of CCS-related tracer research by addressing these diverse aspects and by translating this to the challenges of monitoring of CO2 storage in the marine environment. It's a great contribution and will be a helpful guidance on aspects to consider for the STEMM-CCS tracer approach."

The research team from the universities of Edinburgh and Strathclyde, in partnership with the National Geosequestration Laboratory (CSIRO) in Australia, identified the key challenges to using tracers for offshore monitoring, which should be the focus of future research.

Their work identified issues such as the potential lifespan of tracer chemicals over long timeframes, tracer behaviour in marine sediments or CO2 bubble streams, possible legal constraints and environmental effects, and how best to sample the tracers.

These issues will directly affect the selection of appropriate tracers, the injection programme and concentrations necessary for their reliable detection as well as appropriate sampling approaches. The paper suggests a programme of work to address these uncertainties and inform any future field trials.

The research is expected to prove valuable to STEMM-CCS, a project funded by the European Union's Horizon 2020 programme to deliver new approaches, methodologies and tools for monitoring offshore CCS sites. This includes a CO2 release experiment in the UK North Sea at the prospective Goldeneye storage site.

Dr Jen Roberts, from the University of Strathclyde and the paper's lead author, commented, "Our research paper has direct relevance to ongoing and future research into the use of chemical tracers in monitoring CO2 storage. The work also underlines the value of a networked CCS community and our knowledge sharing activities, which will move our knowledge forward and highlight issues for future projects to address as well as building international interest and capability."

More information

www.sccs.org.uk

Transport and storage news

DOE funding for offshore CO2 storage in Gulf of Mexico

www.netl.doe.gov

The U.S. Department of Energy's Office of Fossil Energy (FE) has selected two projects to receive $8 million in federal funding to assess offshore geologic storage of carbon dioxide (CO2) and technology development in the Gulf of Mexico.

The new projects will focus on assembling the knowledge base required for secure, long-term, large-scale CO2 storage, with or without enhanced hydrocarbon recovery, and assessing technology-development needs (infrastructure, operational, monitoring), which differ from those onshore.

The projects were selected as part of FE's Carbon Storage Program, which advances the development and validation of technologies that enable safe, cost-effective, and permanent geologic storage of CO2. The National Energy Technology Laboratory (NETL) will manage the projects, described below:

• Southeast Regional Carbon Storage Partnership: Offshore Gulf of Mexico—The Southern States Energy Board (Peachtree Corners, GA) will undertake a project with three primary objectives: (1) combine the capabilities and experience of industry, academia, and government to develop and validate key technologies and best practices to ensure safe, long-term, economically viable carbon storage in offshore environments; (2) facilitate the development of technology-focused permitting processes needed by industry and regulators; and (3) provide a comprehensive assessment of the potential to implement offshore CO2 storage in all state waters and the Bureau of Ocean Energy Management's Outer Continental Shelf Oil and Gas Leasing Program planning areas within the Gulf of Mexico.

• Offshore Gulf of Mexico Partnership for Carbon Storage—Resources and Technology Development—The University of Texas at Austin (Austin, TX) will undertake five activities to support safe, long-term CO2 storage in offshore geologic settings: (1) offshore storage resources characterization; (2) risk assessment, simulation, and modeling; (3) monitoring, verification, accounting; (4) infrastructure, operations, and permitting assessment; and (5) knowledge dissemination.