Carbon Capture Journal

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- With urgent action UK could achieve net zero emissions by 2050
- Catalyst opens way to CO2 capture in conversion of coal to liquid fuels
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New IPCC report calls for drastic upscaling of climate ambition

In the IPCC report support for CCS is identified as critical in limiting global warming to 1.5°C, and most pathways to achieving this involve CCS and BECCS. The EU has also recognised that it must have greter ambition in its climate targets and MEPs have recognised the vital role that CCS technologies will play in reducing industrial emissions, says Bellona.

The IPCC's long-awaited Special Report 'Global Warming of 1.5°C' issued an alarming message to policy makers calling for 'rapid and far-reaching' transitions in land, energy, industry, buildings, transport and cities, in order to keep global temperature rise below the 1.5°C threshold. We take a closer look at what the report's findings will mean for transport and heavy industry sectors.

One of the report's key findings is that we are already witnessing the consequences of a 1°C increase of global temperatures in the form of more extreme weather patterns, rising sea levels, and diminishing Arctic sea ice, among others. The report, furthermore, urges for global anthropogenic CO2 emissions to be cut by 45% from 2010 levels by 2030, reaching net zero by 2050, which in turn would require any remaining emissions to be balanced by removing CO2 from the air.

In other words, nearly every country will have to significantly re-think and scale up its commitments under the Paris Agreement. A recent Climate Action Tracker assessment shows just how difficult this task will be, as only seven countries' national climate pledges today are compatible with the targets of the Paris Agreement. The majority, including the European Union, are failing to even commit to sufficient emission cuts on paper

For heavy industry sectors, which currently account for a quarter of global emissions, the outlook isn't much better. The report points out that emission reductions through energy- and process efficiency will not be sufficient to limit warming to below 1.5°C or 2°C. The IPCC stresses that a 75-90% reduction in emissions by 2050 would be needed.

Once again, in this report Carbon Capture and Storage (CCS) technology plays an important role in electricity generation, yet there is just a side-mention of its application in industrial activities, which is an untapped and essential resource for reducing emissions from this sector.

CCS is identified in most pathways to achieving the 1.5°C goal and mitigation costs are significantly increased without CCS and BECCS.

Will the EU live up to its claimed 'climate leader' title?

While clearly running behind schedule, the EU has ample opportunities lined up to boost the ambition level of its targets and policies, among which is the ongoing work of the Commission on its long term decarbonisation strategy to achieve net zero emissions in 2050.

Critically, the pathways consistent with the Paris Agreement show a huge decline of coal power to a near-zero share of global electricity production (from approximately 40% today). If the EU is serious about its climate leadership, it will have to fix its own house, notably Germany and Poland, who seem hell-bent on preserving their coal power for the foreseeable future despite the implications made clear by this report. Germany's proposed 2035 phase-out of coal is not in line with the EU's stated ambitions.

European Parliament calls for higher ambition and rejects anti-CCS recital

The European Parliament voted on its position prior to the COP24 in Katowice, Poland, later this year. Key points of this vote include a rejection of an absurd Recital which wrongfully dismissed the value of Carbon Capture and Storage in climate change mitigation, and a paragraph calling on the Commission to increase its emissions reduction targets from 45% to 55% compared to 1990 levels.

Bellona's President and Founder, Frederic Hauge, commented after the vote:

"Today's vote marks a vital victory for all those fighting for evidence-based, ambitious climate policy. MEPs have sent a decisive signal to the European Commission that they not only want greater ambition on climate targets in the forthcoming Long Term Strategy, but also that they recognise the vital role that CCS technologies will have to play in reducing industrial emissions"

"For too long, DG CLIMA has fallen back on the lazy assumption that because CCS progress in Europe has been slower than expected, we therefore can't rely on it in the future. The science tells us otherwise and now the Parliament has challenged the Commission to re-think its approach to this important technology, while also calling for a more ambitious target of reducing emissions to 55% below 1990 levels by 2030."

"Nonetheless, the vote was close, implying more work is needed to disseminate scientific research and the importance of this technology, which plays a critical role in all pathways which are in line with the Paris Agreement."

More information

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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:

Delegates at Carbon Capture Mumbai learnt about CCUS in Asia at the event run by the Indian Institute of Technology Department of Earth Sciences with Carbon Capture Journal

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Leaders - CCS in Asia

Projects and policy

Capture and utilisation

Transport and storage

Carbon capture making strides in India

Carbon capture, utilisation and storage is making strides in India and Indonesia, as we learned at the CCUS event run by the Indian Institute of Technology Department of Earth Sciences in Mumbai on October 11-12, together with Carbon Capture Journal.
By Karl Jeffery

Carbon capture, utilisation and storage is making strides in India and Indonesia, as we learned at the CCUS conference in Mumbai on October 11-12, organised by Indian Institute of Technology department of Earth Sciences, together with Carbon Capture Journal.

Highlights included India's state oil company ONGC talking about its plans to test CO2 EOR on onshore oil wells; Carbon Clean Solutions, building on its success with the first non-subsidized CO2 to chemicals plant; and Jupiter Oxygen's development of technology to combust coal in high purity oxygen thus creating a flue gas of nearly pure CO2.

Also the Jawaharlal Nehru Centre for Advanced Scientific Research developing catalysts for turning CO2 into methanol at a market price; and the Asia Development Bank, setting up CCUS 'centres of excellence' across Asia, partly with financial support from the UK government.

Delegates enjoying a morning coffee at the event in Mumbai run by the Indian Institute of Technology Department of Earth Sciences with Carbon Capture Journal

We heard analysis from the World Bank onto where the business opportunities have been seen to date in carbon capture and storage – yes there are some. The answer – mainly in the oil and gas industry.

This conference report is structured first with projects, then with technology, then with financial aspects.

Carbon capture projects in Asia

Carbon capture projects in Asia presented at the conference include ONGC and NTPC exploring CCS with CO2 + EOR; Essar Oil looking at CO2 injected into coal bed methane in the Cambey Basin; and Indonesia setting up a 'centre of excellence' for CCUS, including developing a first project injecting CO2 in a shallow reservoir.

ONGC

O. N. Gyani from Indian state oil company Oil and Natural Gas Corporation (ONGC) said that ONGC has signed a memorandum of understanding with a power company to explore the possibilities of CO2 for enhanced oil recovery.

Its studies have shown that the average contribution of the CO2 is to push out 3 barrels of oil per tonne CO2, and the maximum is 7, he said.

However the costs are likely to be high, due to CO2 being expected to be highly corrosive. This leads to a ballpark estimate of $85/ barrel of oil produced using CO2 EOR, including allowance for $32/ tonne paid for the CO2.

It wants to reduce the breakeven price to $50, a price where oil companies are typically sanctioning projects today. The $85 price can be "taken as a first assessment," he said.

The company is employing an expert to explore other CO2 sources, not necessarily from power – for example, industry, heat and agriculture.

India has already started experimenting with enhanced oil recovery, and it now generates 3 per cent of Indian oil production. This starts with WAG (water alternating gas), then polymer technology (started this year, 2018).

Through these methods the company has been able to maintain production at the same level as oilfields decline.

India's Prime Minister Narendra Modi has set a goal of reducing oil imports by 10 per cent by 2022, which will require more use of enhanced oil recovery, Mr Gyani said.

India also has aims to reduce its CO2 emissions due to the Paris agreement, and sees CO2 EOR as a contribution to that, particularly as it has seen prices for capture reducing from $70 to $35 per tonne.

To get the full benefit of CO2 EOR, the pressures have to be high enough (both in the reservoir and the CO2) for the CO2 to be miscible in the oil (form a homogenous mixture) – because then it has benefits of reducing the viscosity and surface tension of oil, rather than just pushing it out of the reservoir (like a water flood).

ONGC discovered 6 out of 7 of all producing basins in India, and pioneered deepwater exploration in India, he said. It has 289 offshore installations, and 261 onshore installations.

Mr O. N. Gyani from Indian state oil company Oil and Natural Gas Corporation. ONGC is working with a power company to explore the possibilities of CO2 for enhanced oil recovery

National Thermal Power Company

India's coal power company NTPC (National Thermal Power Company) is exploring CO2 EOR, said P D Hirani, from NTPC's Energy Technology Research Alliance (NETRA).

The company is looking at using algae to absorb CO2 and turn it into biomass fuel. It is looking at soda ash, which can be made using CO2, "in a big way".

NPTC has a MOU with an oil company to try CO2 for enhanced oil recovery, he said, including a plan to build a 50-60km CO2 pipeline.

Mr Hirani said that India is bringing in regulations for coal power companies for Sox and NOx control, and could pursue a similar path with CO2 control. "I'm pretty sure it [CCS] will be made mandatory after some time."

NTPC is the 6th largest power supplier in the world by megawatts generated, he said. It has 53,000 MW of power generation capacity in operation, and 20,000 MW under construction. It provides 17.7 per cent of India's generation capacity, and 24 per cent of its actual power (because its generation is more efficient so runs at a higher utilisation than average for the country).

India has a complex position on global warming, he said. On one hand, it is still a developing country, and has yet to see the benefits which go with being a developed economy. So it seems fair that developed economies should pay the costs of global warming mitigation.

On the other hand India may suffer more than other countries if climate change does occur. A third issue is that 20 per cent of the population does not have electricity, and it will not help if some of existing generation capacity is used to run carbon capture plants. And India has also ratified the Paris agreement so has obligations under that.

India's plans for 2015 to 2022 are to increase wind power by 23.7 GW to 60 GW, solar from 4 GW to 100 GW, biomass from 4.4 GW to 10 GW, nuclear from 4.3 GW to 63 GW (by 2032).

Essar Oil

Vilas Tawde from Essar Oil and Gas Exploration and Production said that the company is doing a survey of its Cambey basin, looking for ways to inject CO2 into coal bed methane. The main concern will be cost of providing and transporting CO2 to the site, and whether the overall finances work.

The company pioneered coal bed methane in 1992-1993, he said, investing $250m in it. The central government has come up with a marketing policy for gas from CBM, looking at ensuring that it is cheaper than LNG, the alternative source of gas for India. It needs to be available for under $9.3 / MMBtu, he said.

Indonesia's CCS COE

Indonesia has established a CCUS centre of excellence (COE), run jointly by oil and gas research centre Lemigas, and research institution Institut Teknologi Bandung, with funding from the Asian Development Bank.

Indonesia has committed to reduce its emissions by 29 per cent, with a promise to increase that to 41 per cent "with international support". This funding is part of that "international support", since it comes partly from the UK government.

Indonesia has a lot of gas reserves which high

CO2 content which it would like to produce, and many depleted oil fields which could be used to store CO2, said Rachmat Sule, manager of the Indonesia centre of excellence for carbon capture.

Studies have been done in carbon storage possibilities since the beginning of 2000, by Lemigas. Since 2010, focussed effort has gone into one CCS project, "Gundih", managed by the CCS Centre of Excellence.

The centre of excellence research team received grant money from Japan, which was spent largely on subsurface survey equipment, including seismic data recording units, borehole data acquisition, EM and gravity.

It has identified a shallow reservoir suitable for storing of CO2, and anticipates a storage cost of $55/ tonne. The project aims to capture 30 tonnes per day of CO2 from gas processing, or 20,000 tonnes over its lifetime.

Rachmat Sule, manager of the Indonesia centre of excellence for carbon capture. Indonesia has established a CCUS centre of excellence, run jointly by oil and gas research centre Lemigas, and research institution Institut Teknologi Bandung, with funding from the Asian Development Bank

Technology developments in India

Interesting technology developments in and around India include Carbon Clean Solutions' low cost solvents, Jupiter Oxygen's oxy-combustion system, a system to separate gas with much smaller equipment based on a rotating drum, and better catalysts to make methanol from CO2.

Carbon Clean Solutions

Carbon Clean Solutions Limited (CCSL), a UK-based leader in low-cost carbon capture and storage technology with founders from and operations in India, has developed a solvent for carbon capture which is less corrosive, and requires less energy and space than other solvents on the market.

CCSL provides its technology to the first subsidy free CO2-to-chemicals plant in India, where the solvent is used to capture CO2 from the flue of a 10MW coal fired power station. The plant was commissioned in October 2016.

The CO2 is sold to a company which uses it to make soda ash, formed from reacting CO2 with ammonia, water and salt, at a cost of $35 per tonne. "We exceeded our expectations for cost, as we initially anticipated CO2 capture to be $40 per tonne. It was a fantastic milestone for us", said Ramesh Kumar, team leader, Carbon Clean Solutions.

The company now has a project in development for Vishnu Chemicals in India, producing 168 tonnes of CO2 per day, which the company uses for its own purposes.

In a pilot project at EON Netherlands, running a 6.5 tonnes per day plant over 1000 hours, CCSL's solvents resulted in 15 times less corrosion, 10 times lower ammonia emissions, 50 times lower aerosol emissions, and almost zero degradation of the solvent compared to other solvents tested.

"Our solvent was trialled at Technology Centre Mongstad, Norway, and was found to be the only solvent, during the trial year, the centre had tested with parts per billion level emission", Mr Kumar said.

Earlier this year CCSL completed concept study for a waste to energy plant in Norway with design capacity to capture 1600 tonnes/day CO2. The technology is now used at 30 sites around the world in total.

The company offers a number of business models, including licensing the use of the solvent and project management.

The philosophy that underlies the company's technology is to develop a solvent which would combine the strengths of amines and salts.

CO2 reacts quickly and easily with amines, which means that the required surface area for the reaction can be relatively small. The disadvantage is that you then need a larger amount of heat to disassociate the amine from the CO2 in the separate stripper column.

"Another disadvantages with amines is that if any amine is released to the environment it is very dangerous. Amines are also corrosive", Mr Kumar said.

They can degrade faster, so a large amount of "make up solvent" is required because, which carries associated waste disposal costs for the degraded solvent.

In contrast, salts have a slow reaction, with lower energy, but need a bigger reaction surface area, so require larger equipment. They need less energy to dis-associate, are less corrosive and degrade slower.

CCSL's core idea has been to develop a new molecule which could combine the strengths of both in the right way, so it would be less corrosive, would not require so much heat and would not degrade quickly.

The company developed a new solvent which, in trials, demonstrated 10 x less corrosive, reduced solvent disposal costs by 75 per cent (and hence less need for new solvent), 50 per cent less thermal energy, and lower capex.

Carbon Clean Solutions' CEO Aniruddha Sharma noted that there have been experiments injecting CO_2 into cement, which has been shown to increase strength of the cement, as well as reduce water consumption. "These options are opening up now. There are many new exciting opportunities," he said.

U P Pani from Jupiter Oxygen. Jupiter Oxygen is expecting results shortly from a feasibility study in Xinjiang Province (Western China), for the retrofit of a 55 MWe coal-fired power plant with JOC's CO_2 capture technologies

Jupiter Oxygen

Jupiter Oxygen Corporation (JOC) is a clean energy technology company, based Illinois, USA. Its application of high flame temperature oxy-combustion involves fitting the technology to existing and new power plants and industrial facilities. JOC's oxy-combustion technology generates highly concentrated CO_2 in the flue gas and enables cost-effective carbon capture. Co-benefits from applying JOC's oxy-combustion based carbon capture technology include air pollutant control, process water recycling and making CO_2 available as a saleable product.

The CO_2 can be combined with nitrogen (from the air separation process) and both used together in enhanced gas recovery – the company is looking at coal bed methane fields in India and China for integrated carbon capture, utilization and storage (CCUS) project development.

Jupiter Oxygen is expecting results shortly from a feasibility study in Xinjiang Province (Western China), for the retrofit of a 55 MWe coal-fired power plant with JOC's CO_2 capture technologies. Furthermore, Jupiter Oxygen has identified CCUS ECBM demonstration project sites in West Bengal, India, and recommended to the Department of Power in West Bengal to develop those in collaboration with the Indian Institute of Technology Bombay and industry partners.

There are 2 to 2.6 trillion cubic metres of coalbed methane in place in India (ARI, 2015). 25% of the methane in place is recoverable via conventional CBM techniques and estimated additional 20% are recoverable via enhanced coal bed methane (ECBM: using CO_2 and N_2), said U P Pani from Jupiter Oxygen. West Bengal has an advanced CBM production, ready for ECBM application and field testing.

Trilok Corporation

Trilok Corporation of Mumbai in collaboration with Process Intensification consultants of Hyderabad is developing a gas separation technology based on a rotating absorber). It potentially enables gas separation with a much smaller sized separation equipment than a standard CO_2 absorption system.

The company sees the technology similar to how computers have been gradually miniaturised, said D P Rao of Process Intensification consultants, and a retired chemical engineering professor from Indian Institute of Technology Kanpur.

To illustrate the size of a standard carbon capture system, if you want to capture CO_2 from a flue gas of a typical 500 MW power plant, you can have 500 t0 to 750m^3 per second of gas in the flue, which means towers 250 to 375m^2 cross sectional area (375m^2 area means 22m diameter).

Trilok's method uses a rotating packaged bed, and absorption. Rather than use gravity (with fluids falling down the column as gases rise), it uses centrifugal force, with the spinning sending the gas out of the rotating bed.

The technology is not new – it was patented in the UK in 1983. The technology has been called "HIGEE" for High Gravity Technology.

Until now, the packing material has been very costly, but it can be made at a lower cost with 3D printing.

There are many other business applications which might benefit from a smaller gas separation technology, including de-oxygenating boiler feed water, or capturing SO_2 from flue gas of marine engines.

The company had a unit on trial in North Dakota University, Energy & Environmental Research Centre for CO_2 capture and another for deoxygenation of boiler feed water supplied to BPCL R&D centre, Nodia, India. Based on the trails at the North Dakota University. Trilok was awarded a contract CO_2 Solutions, Canada to design and fabricate a unit for handling 100 tonnes of flue gas a day.

A rotating cylindrical annular adsorber with temperature swing is under development for post-combustion CO2 capture and for fractionation of air required for oxy- combustion. The adsorbent bed has different sections for enriching the material with gas and desorbing the gas from the material, so during each rotation it goes through a complete cycle of enriching and desorbing. There can be rotation speed of 1 revolution per 1 to 5 minutes.

This is large rotating equipment – similar to the rotating hearth furnace used in iron making, he said.

Better catalysts for making methanol

Sebastian C. Peter from the Jawaharlal Nehru Centre for Advanced Scientific Research is developing catalysts which can convert CO2 into chemicals and fuels, including methanol and agricultural feedstocks.

There are lots of ways to do it but "most are not economical at scale," he said.

CO2 can be reacted to form methane, methanol, dimethyl ether and more.

Methanol is predicted to see an increase in demand from 60.7mt per year in 2013 to 109 mtpa in 2023. Chinese part of this will grow from 30 to 67.5. India's demand is currently 1.5mt, he said.

There have been predictions that methanol will be the "fuel of the future" since 1973, since it can be made in a variety of ways, including clean and non-fossil ones.

Mr Peter believes it can be possible to make methanol using CO2 (captured from CO2 flue gases), hydrogen (made or purchased), electricity and a catalyst (designed by JNCASR). It has developed a proof of concept at lab scale which converts 5kg CO2 a day to methanol.

The cost of making methanol through this process could work out at around $300 / tonne, including $55 for the CO2, $111 for hydrogen, $130 for electricity, and $10 for the catalyst, which is similar to the market price.

Financial aspects of CCUS

We heard ideas from the Asian Development Bank and International Energy Agency about where CCS financials seem to be working so far – and ADB's work, partly funded by the UK government, to set up CCS 'centres of excellence' around Asia.

The Asian Development Bank has set up three "centres of excellence" (COEs) in CCS, two in China (in Guangdong and Shanghai) and one in Indonesia.

Apart from Indonesia and PRC, ADB has also done "early assessment" on CCS in Bangladesh, Thailand, Vietnam and the Philippines.

The Guangdong COE was an extension of UK- China CCS COE. It has worked on reports on cost reduction, application of multiple policy instruments, IPR protection and knowledge transfer said Darshak Mehta, CCS technology expert (Consultant) with the Asian Development Bank

The Shanghai COE has worked on membrane separation of CO2, Life cycle assessment, optimisation of the process in the steel sector etc.

The Indonesia COE is supporting government policy, ranking fields on EOR, supporting the Gundih project, as well as doing basic research on membranes.

Altogether, the Centres of Excellence can perform a number of different roles, including ratifying and validating new projects, advising on regulations or driving research in more theoretical aspects Mr Mehta said.

Pradeep Perera, Energy Head (India) with ADB. For future projects, Dr Perera believes that a minimum size of 50-100MW is appropriate, to make the finances work, and it is better if private sector companies can share 10-20 per cent of the total cost

ADB is open to support CCUS proposals in Asia if they meet the requirements of the bank he said.

Asia Development Bank's CCUS fund is


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partly funded by the UK government, which is putting $35m in ADB's trust fund and $35m in the World Bank's CCUS trust fund. This is connected to the UK's part of the $100bn a year climate financing from rich countries to poorer ones, as agreed in the Paris 2015 climate meeting.

CCU has a "perception of being one of the costlier CO2 abatement options," said Dr. Pradeep Perera, Energy Head (India) with ADB. But it could be feasible if the price was $30 a ton.

In China, the government has provided an incentive for carbon capture and storage, promising to agree a power station extra hours of operation is used (in China, the number of hours of operation is set by the government).

In case of PRC the operating hours of power stations are decided by the authorities. In order to encourage CCS, the authorities in Guangdong have devised a policy instrument which allows the power plants with CCS to operate for longer hours. It helps in meeting additional expenses of CCS and also acts as an additional financial incentive. However India has no such government incentives.

ADB has kept a close eye on the costs of CCS projects around the world, observing that the costs of the Canadian Boundary Dam project rose from $1.3bn original estimate to $1.5bn, and the $1.3bn included $800m on the capture and $500m on retrofitting the power plant. The operator had to pay C$12m penalties in 2014 for failing to deliver the contracted amount of CO2.

The PetroNova project, near Houston, the world's largest post combustion CO2 capture system, 240 MW, fitted to a coal burning power plant, with CO2 for EOR. It was funded with a $190m US government loan, a $250m loan from the Japanese government, and $300m in equity from NRG Energy Inc and JX Nippon Oil & Gas Exploration Corp.

For future projects, Dr Perera believes that a minimum size of 50-100MW is appropriate, to make the finances work, and it is better if private sector companies can share 10-20 per cent of the total cost.

Dr Perera said it is possible that large scale CCS "may not be feasible in the Indian context given other challenges India has".

"But with global level global warming (discussions) there may be a situation where India will have to act with a greater vigour. Under these circumstances there is a need for India to be ready," he said.

International Energy Agency

Tristan Stanley, energy analyst with the International Energy Agency, observes that CCS is proving to work most of all on projects linked to the oil and gas sector (such as enhanced oil recovery or separating CO2 from a gas production stream), and usually works well when it is a 'small additional step' to what was being done already.

Perhaps it is easier if we expect the development of a CCS industry to be slow, "like any other industrial revolution". Consider that CCS is most ready to take off in the US, "and they've been doing it for 30 years." The majority of CCUS projects are in the US, he noted.

"It isn't a technology we can just roll out. There's a lot of work that needs to go into each stage of storage and development," he said. "The renewables industry didn't get there overnight."

IEA calculates that 80 per cent of private investment in CCUS so far has been underpinned by oil and gas sales. The direct revenue could be attributed 25 per cent from sale of CO2, 54 per cent from direct oil and gas sales, 1 per cent from securing tax credits, 8 per cent from industrial products sales, and 12 per cent from regulated electricity sales.

IEA has been looking for "easy places to capture CO2", such as CO2 when hydrogen is made from steam methane reforming, biofuel production, and natural gas processing.

If you start with the question "where in the world can CO2 be extracted for the lowest cost, and how much of it," IEA calculates that 450 mega tonnes of CO2 a year could be captured for under $40 a tonne, which is approximately the total emissions of Australia.

If there is a market looking for the cheapest CO2 it can find, that encourages entrepreneurs to think up ways to provide CO2 more cheaply than the competition, he said.

Mr Stanley believes that CCU, while being "a very important avenue", should not be seen as an alternative to CO2 storage.

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MN Dastur – gasification "better pathway to CCS in India"

For India to implement carbon capture and storage, it may be better to look at developing entirely new industries around gasified coal, rather than retrofit CCS on its coal power stations, suggests Atanu Mukherjee, president of Kolkata-based metals & energy consultancy MN Dastur & Co.

For India to develop CCS, it may be easier to look at developing entirely new industries from gasified coal, such as making steel, ammonia (a feedstock for fertiliser urea), methanol and even liquid fuels from coal gas, rather than try to install carbon capture on the existing coal power stations, says Atanu Mukherjee, President of Kolkata-based metals & energy consultancy MN Dastur & Co.

MN Dastur consults to the metals, mining and energy industries in India.

For these gasified coal based businesses to be viable, it would be necessary to source high ash coals with consistent compositions at about $15/tonne and blend it with sweeteners, rather than the typical price paid for Indian low rank coals at $30/tonne, he said.

Even in the case of captive coal sourcing, the price of coal sourced through coal block auctions would raise the price of coal much beyond the viable cost for gasification , and one will likely land up in a situation where no coal blocks for gasification get allocated, Mr Mukherjee says.

But if coal were made available for gasification and carbon capture at a lower price, the benefits it would get from these new industries through jobs, tax revenue and economic multiplier effects would far outweigh and offset any losses due to the lower coal price.

Perhaps a financial solution could be devised using investment tax credits and tax credits for gasification and carbon capture, so that the effective cost of coal for gasification is about $15, but the coal company receives the market price or levelized coal cost after taking auction price into account, he says.

In contrast, retrofitting carbon capture on the country's aging and mostly sub-critical coal power station structure would be very difficult and expensive, especially with so many problems with the power sector as it is, as the power generation and distribution system business model is broken, Mr Mukherjee believes.

Carbon capture would also increase demands for power from a system already unable to meet demand. And of course it would also increase the power cost to a developing country's population.

Using gasified coal

Coal gasification is a process where coal is heated to above 700 degree C, causing it to turn into a gas – methane, hydrogen, carbon monoxide, carbon dioxide and water. These gases are then separated, the CO_2 is removed for sequestration, and the CO, hydrogen and CH_4 can be used as a feedstock for other industrial processes.

The gasified coal can be used as a feedstock for many processes, including making steel , liquid fuels and plastics.

In particular, if vehicles could run on more carbon efficient liquid fuels, like methanol, from coal with the CO_2 captured along the way, the country would need to spend less on imported oil, without worrying about the increased CO_2 emissions.

India may face difficulties importing oil from Iran, one of its main suppliers, when US sanctions come into force in November this year. India imports over 30% of its oil, mainly from Iran and Saudi Arabia, every year. India also imports methanol from the Middle East, which the output from these plants could displace.

The coal gas could be used to make steel through the much more carbon efficient direct reduction route. Gasification could also provide gas for standard uses at a much lower cost than importing natural gas through the LNG route at about $12 per mmbtu for gas delivered to India via LNG shipping. There is limited availability of natural gas in India and access is rationed, Mr Mukherjee says.

Atanu Mukherjee, president of metals & energy consultancy MN Dastur & Co.

If designed and implemented right, gasification can work comfortably on high ash low rank coals – which is a large part of the 300bn tonnes of coal India has, Mr Mukherjee says.

U.S. Department of Energy

Mr Mukherjee's consultancy MN Dastur announced a collaboration with the US Department of Energy, September 2018, to work together in finding ways to advance coal gasification with carbon capture, utilization and storage in India. Dastur will work with the DOE and the Department's National Carbon Capture Center (NCCC) on "technology scaling, economic viability, investment enablement, policy advocacy and strategic and operational designs, both at the government and the enterprise level," it said.

More information

www.dastur.com

EU failing with commercial deployment of carbon capture say Auditors

EU action to support carbon capture and storage and innovative renewables has not succeeded, according to a new report from the European Court of Auditors.

Between 2008 and 2017, ambitious targets were set, but EU support for demonstration projects achieved little in terms of projects delivered and results achieved, say the auditors. The EU needs to adapt its new Innovation Fund to reach its objectives, they add.

In 2009, the EU launched two large funding programmes to support carbon capture and storage and innovative renewables: the European Energy Programme for Recovery and the New Entrants' Reserve 300 programme. With an overall spending target of €3.7 billion, both programmes set ambitious targets for the delivery of carbon capture and innovative renewables. Under the 2015 Paris Agreement, the EU is committed to at least a 40% reduction in greenhouse gas emissions by 2030, complementing its ambition to achieve a low-carbon economy by 2050.

The auditors looked at the design, management and coordination of both programmes, and assessed whether they had made the progress expected in terms of helping carbon capture and innovative renewables advance towards commercial deployment. They visited projects in Germany, Spain, the Netherlands, Poland and the United Kingdom.

They found that the Energy Programme for Recovery contributed positively to the development of the offshore wind sector, but fell short of its ambitions for carbon capture. Meanwhile, the New Entrants' Reserve programme delivered no successful carbon-storage projects and made little progress in supporting the demonstration of a wider range of innovative renewable-energy technologies.

"The EU strives to be the global leader in fighting climate change", said Samo Jereb, the Member of the European Court of Auditors responsible for the report. "To be on track, it needs to draw lessons from past failures, design better support mechanisms for innovative low-carbon technologies and ensure full accountability for public resources used to meet this challenge."

Recommendations

The EU is now preparing to launch the Innovation Fund in 2021 to help speed up the transition to a low-carbon economy. With this in mind, the auditors recommend that the European Commission should:

- increase the potential for effective EU support for such projects;
- improve the project selection and decision-making procedures for the forthcoming Innovation Fund, and ensure its flexibility to respond to external developments;
- enhance its internal coordination for more coherent targeting of EU support;
- ensure accountability for the Innovation Fund and the New Entrants' Reserve Programme.

Adverse investment conditions affected both programmes, note the auditors. Uncertainty in regulatory frameworks and policies hampered or delayed the progress of many innovative renewable energy and carbon-capture projects. The report also highlights the key role of volatile and lower-thanexpected carbon market prices after 2011 in the failure of carbon capture and storage deployment.

The auditors found that the design of the New Entrants' Reserve programme limited the Commission's and the Member States' ability to respond effectively to changing circumstances. Project selection and decision-making processes were complex, and other design features constrained the programme's flexibility. Major improvement is required in coordination to enhance coherence and bring more clarity, say the auditors. They also raise concerns about the lack of clear accountability and control arrangements for the New Entrants' Reserve Programme. Funds for this programme did not pass through the EU budget, and are not recorded in the EU balance sheet.

John Scowcroft, Executive Adviser for Europe at the Global CCS Institute, said it is important for the EU and other key stakeholders to build on the conclusions and observations made in this report and incorporate them as we move forward to accelerate the deployment of CCS in Europe to reach global climate targets.

"Despite previous efforts to accelerate the deployment of CCS in Europe, we are still lagging behind compared to other regions of the world. We hope that this report will help guide policy makers working on the Innovation fund to ensure it will help get CCS projects off the ground. The lessons learnt and the informed recommendations put forward by the European Court of Auditors should contribute to further improvements on how the European Union supports CCS in the near-future. Support funding mechanisms need to be designed to enable investment and development of full-scale CCS projects and transport and storage infrastructure."

The Global CCS Institute was interviewed as part of the report given its role as manager of the European CCS Demonstration Network. The report has highlighted the important role of the Network in sharing knowledge gained on different CCS projects.

More information

www.eca.europa.eu

With urgent action UK could achieve net zero emissions by 2050

A joint report by the Royal Academy of Engineering and Royal Society presents an ambitious plan for how the UK can lead the way in deploying greenhouse gas removal (GGR) technologies to achieve net-zero carbon emissions by 2050. www.raeng.org.uk/greenhousegasremoval

It is the first time that a range of GGR technologies have been assessed for their real-world potential in being used together to meet climate goals in the UK over the next 30 years.

The report's authors state that while the UK's first priority must be to maintain efforts to rapidly cut greenhouse gas emissions, GGR technologies have a role to play in counteracting emissions from aviation and agriculture, where the scope to completely reduce emissions is limited. However, to meet climate targets significant action is essential, starting now. Bringing the UK to net-zero emissions in 2050 will require annual removal of an estimated 130 megatonnes of CO2, even with stringent reductions in emissions.

The report also considers the global picture and outlines a scenario in which a portfolio of GGR technologies can be implemented together to achieve carbon removal across the world by 2100 to meet the Paris Agreement goals. Biological solutions like planting trees will become saturated by the end of the century and other GGR technologies will need to be developed and used in the longer term.

The technologies discussed in the report range from well-known and ready to deploy methods, such as forestation, to more speculative technologies like direct air capture, which aims to use chemical processes to remove CO2 from the atmosphere.

Each technology is assessed on its readiness for deployment in the time scale required, potential for scalability, costs, environmental and social impacts and how much of a 'dent' it can make in removing carbon to meet the targets.

Professor Gideon Henderson FRS, Professor of Earth Science at the University of Oxford and chair of the report working group, says, "If the UK acts now on greenhouse gas removal, we can reach national emissions targets and show how a major industrialised economy can play a leading role in meeting the goals of the Paris Agreement.

"In this report we've identified the available GGR technologies, how they might be used together for maximum effect, and how their phased development and deployment could enable the urgent action required to avoid the devastating impact of climate change.

The UK 2050 net-zero scenario

GGR technologies suitable for the UK to use to meet net-zero emissions by 2050 include:

• Ready to use GGR methods such as forestation, habitat restoration, soil carbon sequestration, and building with wood or carbonated waste could provide just over a quarter of the target to reach net zero emissions.

• Biochar, enhanced terrestrial weathering in agricultural soils, direct air capture (DACCS), and bioenergy with carbon capture and storage (BECCS) could contribute to the rest of the 2050 target.

What we need to do to achieve net-zero emissions in the UK

• Rapidly increase forestation to 5% of UK land, restore wetlands and salt marshes, and store more carbon in farmland

• Establish an incentive or subsidy system to encourage farmers to use their land to store carbon. This could be part of the framework that replaces the Common Agricultural Policy after the UK leaves the EU.

• Encourage changes in building practice to use wood and cement manufactured with carbonated waste.

• Develop better ways of monitoring the effectiveness of GGR technologies.

• Pursue research into the potential of longer term GGR technologies such as enhanced weathering, biochar, BECCS and DACCS.

• Capitalise on the UK's strengths in engineering and industry to establish the infrastructure required for the storage of CO2.

How to meet the Paris Agreement using GGR technologies

The report also calls for action in a number of key areas in order to meet the overall goals of the Paris Agreement.

• Continue and increase global efforts to reduce emissions of greenhouse gases.

• Implement a global portfolio of GGR technologies now to meet the goals of the Paris Agreement.

• Build carbon capture and storage infrastructure, essential to meeting the scale required for achieving climate goals.

• Encourage investment in the development and piloting of GGR projects to assess their real world potential and understand any environmental and social impacts.

• Establish incentives, for example carbon pricing, to pay for removal of CO2 and encourage business to use a wide portfolio of GGR technologies.

• Establish a framework to govern use of GGR technologies that addresses sustainability and engages the public.

• Build GGR into regulatory frameworks and carbon trading systems.

• Establish international science-based standards for monitoring the effectiveness of GGR technologies and their environmental impacts.

Negative emissions technologies must play significant role

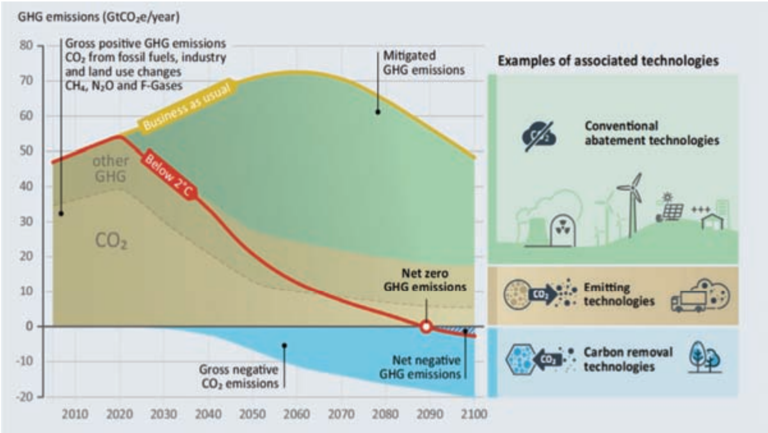
To achieve goals for climate and economic growth, negative emissions technologies that remove and sequester carbon dioxide from the air will need to play a significant role in mitigating climate change, says a new report from the National Academies of Sciences, Engineering, and Medicine.

The report calls for the launch of a substantial research initiative to advance these technologies as soon as possible. Although climate mitigation remains the motivation for global investments in NETs, the committee that carried out the study and wrote the report determined that advances in NETs also could have economic rewards, as intellectual property rights and economic benefits will likely accrue to the nations that develop the best technology.

"Negative emissions technologies are essential to offset carbon dioxide emissions that would be difficult to eliminate and should be viewed as a component of the climate change mitigation portfolio," said Stephen Pacala, the Frederick D. Petrie Professor in Ecology and Evolutionary Biology at Princeton University and chair of the committee. "Most climate mitigation efforts are intended to decrease the rate at which people add carbon from fossil fuel reservoirs to the atmosphere. We focused on the reverse – technologies that take carbon out of the air and put it back into ecosystems and the land. We determined that a substantial research initiative should be launched to advance these promising technologies as soon as possible."

Unlike carbon capture and storage technologies that remove carbon dioxide emissions directly from large point sources such as coal power plants, NETs remove carbon dioxide (the most important greenhouse gas that causes climate change) directly from the atmosphere or enhance natural carbon sinks. Storing the carbon dioxide from NETs has the same impact on the atmosphere and climate as simultaneously preventing an equal amount of carbon dioxide from being emitted.

For example, combustion of a gallon of gasoline releases approximately 10 kilograms (kg) of carbon dioxide in the atmosphere. Capturing 10 kg of carbon dioxide from the atmosphere and permanently sequestering it using a NET has the same effect on atmospheric carbon dioxide as any mitigation method that simultaneously prevents a gallon of gasoline combustion.



Scenario of the role of negative emissions technologies in reaching net zero emissions. SOURCE: UNEP, 2017.

The committee concluded that the NETs available today could be safely scaled up to capture and store a significant fraction of the total emissions both in the U.S. and globally, but not enough to keep total global warming below two degrees Celsius, the target of the Paris agreement. Therefore, a concerted research effort is needed to address the constraints that currently limit deployment of NETs, such as high costs, land and environmental constraints, and energy requirements.

Four land-based negative emissions technologies are ready for large-scale deployment at costs competitive with emissions mitigation strategies, the report says. These technologies include reforestation, changes in forest management, and changes in agricultural practices that enhance soil carbon storage. The fourth NET ready for scale up is "bioenergy with carbon capture and sequestration" – in which plants or plant-based materials are used to produce electricity, liquid fuels, and/or heat, and any carbon dioxide that is produced is captured and sequestered.

However, these four NETs cannot yet provide enough carbon removal at reasonable cost without substantial unintended harm, the report says. Repurposing a significant amount of current agricultural land for growing new forests or feedstocks for bioenergy with carbon capture and sequestration could have significant effects on food availability. Repurposing tropical forest would harm biodiversity. Research could identify ways to soften the land constraint, for instance, by developing crop plants that take up and sequester carbon more efficiently in soils, or by reducing food waste or demand for meat.

Two other negative emissions technologies could be revolutionary, the committee said, because they have high potential capacity to remove carbon. Direct air capture employs chemical processes to capture carbon dioxide from the air, concentrate it, and inject it into a storage reservoir. However, it is currently limited by high cost. There is no commercial driving force for developing direct air capture technologies; therefore, developing a low-cost option will require sustained government investment. Carbon mineralization – which essentially accelerates "weathering" so carbon dioxide from the atmosphere forms a chemical bond with reactive minerals – is currently limited by lack of fundamental understanding.

The committee also examined coastal blue carbon, which involves changing land use and management practices to increase carbon stored in living plants or sediments in coastal ecosystems such as tidal marshlands. Although it has a relatively low potential capacity for removing carbon, the committee concluded that coastal blue carbon warrants continued exploration and support. The cost of the carbon removal is low or zero, because investments in many coastal blue carbon projects target other benefits such as coastal adaptation. An increase in understanding of how sea-level rise, coastal management, and other climate impacts could affect future carbon uptake rates is needed.

The committee found that NETs have not yet received adequate public investment despite expectations that they might provide approximately 30 percent of the net emissions reductions this century. A substantial research investment is needed as soon as practicable, the committee said, to improve existing land-based NETs, make rapid progress on direct air capture and carbon mineralization, and advance NET-enabling research on biofuels and carbon dioxide sequestration.

The report presents multiple reasons to pursue research on NETs. First, states, local governments, corporations, and countries around the world now make substantial investments to reduce their net carbon emissions and plan to increase these expenditures. Some of these efforts already include negative emissions technologies. This means that advances in NETs will benefit the U.S. economy if the intellectual property is held by U.S. companies. Second, as climate damages mount, the U.S. will inevitably take increased action to limit climate change in the future. Third, the U.S. is already making a substantial effort, including the new 45Q rule that provides a tax credit for capture and storage, which would leverage the value of new investments in NET research.

The study was sponsored by the U.S. Department of Energy, National Oceanic and Atmospheric Administration, Environmental Protection Agency, United States Geological Survey, V. Kann Rasmussen Foundation, Linden Trust for Conservation, and Incite Labs, with support from the National Academy of Sciences' Arthur L. Day Fund.

More information

www.nap.edu

Future of UK Oil&Gas is in offshore CO2 storage industry

Prof Stuart Haszeldine, SCCS Director, told the Scottish Affairs Select Committee that CCS offers a lifeline to the UK oil and gas industry as it faces an unavoidable transition to a low-carbon economy, but urgent action is needed by government to seize the opportunity.

A multi-billion-pound industry that can deliver effective climate action and a viable future for the UK's oil and gas industry is being imperilled by slow decision-making within government, Prof Haszeldine told a UK parliamentary committee.

In the week that the UN Intergovernmental Panel on Climate Change's landmark report warned that the world has just 12 years to enact measures that will keep global warming to a maximum of 1.5C, and all scenarios will call on carbon dioxide removal technology.

One year ago, a key industry study showed that a CCS network making use of oil and gas industry expertise and infrastructure could boost the UK economy by an estimated £160 billion between now and 2060.

Evidence already submitted to the Select Committee by the SCCS research partnership stated that:

- The oil and gas industry has the skills, experience, knowledge and assets to develop a profitable CCS industry in the UK.

- Oil and gas infrastructure can be re-used, saving public money on decommissioning and enabling the development of a new offshore CO2 storage industry for the UK.

- Well-managed CO2-EOR will contribute to maximising economic recovery, as well as potentially storing more CO2 than it produces.

- Urgent action is needed by the UK Government, such as joining the dots within government to ensure opportunities are not lost due to a lack of clear responsibility, and ensuring suitable pipelines are preserved for re-use.

Prof Stuart Haszeldine commented, "The future of the oil and gas industry is inextricably linked to CCS. It provides a unique opportunity for the UK's offshore industries to lead on decarbonising Europe's economies, maintaining high-value jobs and avoiding climate chaos."

"The UK has been through three cycles of detailed engineering and finance appraisal to design projects which can securely store carbon. In the remainder of 2018, we can now move on to development. This includes projects, such as Acorn in north east Scotland, where recent studies show that infrastructure and geology can support a large-scale CCS network for permanently storing carbon from Europe as well as the UK. This opens the door to clean heat and transport, and a new generation of low-carbon manufacturing and chemical industries. And work is now underway to evaluate the potential for low-carbon hydrogen production from natural gas brought ashore at the St Fergus Gas Terminal."

"The UK Government is rightly attempting to design a larger scale support system for CCS projects in different regions of the UK but that does not mean waiting. If the UK Government provides relatively low funding and matches Scottish Government finance and support, Acorn could begin operating in 2022. Importantly, this will support the UK oil and gas industry's just transition to a low-carbon economy."

More information

www.sccs.org.uk

Stanford study highlights way to coax emissions back into oil reservoirs

A new analysis looks at what it would take for oil companies to start pumping millions of tons of carbon dioxide into their wells to boost crude production and what it would mean for the climate.

In February 2018, Donald Trump signed into law new tax credits that reward oil companies for capturing carbon dioxide and preventing it from entering the atmosphere – either by burying the gas underground or by pumping it into wells to boost production. These tax credits, which have bipartisan support, are encouraging for those who believe that trapping CO2 from the fossil fuel industry – though no substitute for deploying cleaner energy sources – could help combat runaway climate change while society remains reliant on oil, gas and coal.

As much as 65 million metric tons of carbon dioxide flow into oil recovery projects each year to help drive crude and profits from aging wells. But most of the CO2 comes from natural reservoirs – not refineries, power plants or other sources contributing to climate change. (Image credit: Shutterstock)

Now, a Stanford University analysis published Aug. 15 in the journal Joule suggests another way the government could encourage the oil and gas industry to capture and store carbon. The article proposes a model for how relatively small government payments could pave the way for oil reservoirs to stash away more CO2 than their burned contents unleash.

“If you look at air transport, shipping, heavy-duty land-based transportation, these are uses of fossil fuels that are definitely expected to grow,” said lead author Sally Benson, a professor of energy resources engineering at the School of Earth, Energy & Environmental Sciences (Stanford Earth). “As an insurance policy, getting everybody to contribute to solving this problem is really important, including the oil and gas industry.”

Carbon in, oil out

When injected into reservoirs, carbon dioxide can help drive oil and profits from aging wells. The technique, known as carbon dioxide-enhanced oil recovery, has been in use since the 1970s. Oil companies using it today pump in about two-and-a-half tons of carbon for every barrel of oil produced. “When you do that, the emissions from burning the oil are almost identical to the CO2you’re putting in the reservoir,” said Benson, who co-directs Stanford’s Precourt Institute for Energy.

The problem is that most of the 65 million metric tons of CO2 used in these oil recovery projects each year comes from natural reservoirs – not refineries, power plants or other sources contributing to climate change.

In their analysis, Benson and co-author John Deutch, a professor emeritus at MIT, propose a cost-effective way of encouraging oil and gas companies to double the amount of carbon injected for every barrel of oil and to draw their CO2 from human-related sources. They say a 10-fold increase in the amount drawn from these sources could shrink the nation’s climate emissions by as much as 9.5 percent – even when accounting for the additional oil extraction made possible by injecting all that carbon.

All of this could be done at surprisingly low cost, the researchers claim, if companies start out trapping CO2 from relatively pure streams, like those vented from ethanol and fertilizer plants. According to Benson, experience gained on these projects could then help to drive down the cost of capturing and treating CO2 from mixed emission sources, such as cement and power plants.

Lighting a fire

Benson and Deutch, who is a former head of the Central Intelligence Agency and deputy defense secretary, argue that government should encourage industry to prepare for a future with an economy-wide price on carbon emissions – in part by developing better carbon storage technology.

Doubling the amount of CO2 per barrel of oil compared to the standard practice today, as Benson and Deutch envision, would almost certainly be more expensive for operators. The new analysis suggests it would add at least $22 per ton of injected carbon in a hypothetical scenario where oil costs $100 a barrel.

“That’s a lot of cost for an oil company,” Benson said. “If one company does it and they don’t all do it, then your products are just more expensive than the competition. People just buy the cheapest crude oil they can.”

To overcome those costs and spur development of technology for carbon-negative oil recovery, the researchers suggest the government pilot test something called a reverse Dutch auction. Owners of new oil recovery projects would submit bids to the government specifying how much money they would want as a reward for carbon injection and how much CO2 they expect the project to ultimately sequester.

With this system, Benson and Deutch estimate it would cost the government about $25 per ton of carbon dioxide captured. If 30 projects earned that amount for a decade apiece, the program would trap 264 million tons of CO2, and government spending on the experiment would total $6.6 billion.

For comparison, the newly expanded tax credits offer $35 per ton of CO2 captured and put to use, or $50 per ton if the carbon is simply buried. According to Benson, her proposed pilot program could cost less and provide incentives for a wider variety of companies that may not benefit from a tax credit.

Benson is also an affiliate of the Stanford Woods Institute for the Environment.

More information
www.stanford.edu

Accelerating breakthrough innovation in CCUS - mission innovation report

On September 26–28, 2017, the United States, in conjunction with Saudi Arabia, hosted the Mission Innovation Carbon Capture, Utilization, and Storage (CCUS) Expert's Workshop. The Workshop, held in Houston, Texas, brought together 260 of the world's leading CCUS experts from academia and industry to evaluate the most promising research and development (R&D) avenues for enhancing CCUS processes.

Specifically, the goals of the Workshop were to assess current gaps in CCUS technologies and to identify the most promising directions for basic research (Priority Research Directions, or PRDs) that are needed to achieve long-term global carbon management.

These PRDs encompass opportunities for understanding and improving materials, chemical processes, and other scientific and technical areas required to develop the next-generation technologies needed for efficient, cost-effective management of carbon emissions. The PRDs were created from panel discussions covering four subcategories: Carbon Capture; Carbon Utilization; Carbon Storage; and Cross-Cutting CCUS Topics.

The technologies needed to make CCUS work on an industrial scale are commercially available today, the report says, as is demonstrated by CCUS processes that have been deployed at various sites for a number of years. The PRDs will guide the R&D that will be required to improve current technologies to deliver CCUS at the scale that is expected to be needed in the period 2030–2050.

Priority Research Directions

Capture

• Designing high-performing solvents for CO2 Capture

• Creating environmentally friendly solvent processes for CO2 capture

• Designing tailor-made sorbent materials

• Integrating sorbent materials and processes

• Understanding transport phenomena in membrane materials

• Designing membrane system architectures

• Catapulting combustion into the future

• Producing hydrogen from fossil fuels with CO2 capture

Utilization

• Designing complex interfaces for enhancing hydrocarbon recovery with carbon storage

• Valorizing CO2 by breakthrough catalytic transformations into fuels and chemicals

• Creating new routes to carbon-based functional materials from CO2

• Designing and controlling molecular-scale interactions for electrochemical and photochemical conversion of CO2

• Harnessing multiscale phenomena for high-performance electrochemical and photochemical transformation of CO2

• Accelerating carbon mineralization by harnessing the complexity of solid–liquid interfaces

• Tailoring materials properties to enable carbon storage in products

• Tailoring microbial and bioinspired approaches to CO2 conversion

• Hybridizing electrochemical and biological process for CO2 conversion to fuels, chemical, and nutrients

Storage

• Advancing multiphysics and multiscale fluid flow to achieve gigatonne/year capacity

• Understanding dynamic pressure limits for gigatonne-scale CO2 injection

• Optimizing injection of CO2 by control of the near-well environment

• Developing smart convergence monitoring to demonstrate containment and enable storage site closure

• Realizing smart monitoring to assess anomalies and provide assurance

• Improving characterization of fault and fracture systems

• Achieving next-generation seismic risk forecasting

• Locating, evaluating, and remediating existing and abandoned wells

• Establishing, demonstrating and forecasting well integrity

Crosscutting

• Integrating experiment, simulation, and machine learning across multiple length scales to guide materials discovery and process development

• Coupling basic science and engineering for intensified carbon capture, purification, transport, utilization and storage processes

• Incorporating social aspects into decision-making

• Developing tools to integrate life-cycle technoeconomic, environmental, and social considerations to guide technology portfolio optimization

More information

www.energy.gov/fe

Update on CCS in Europe – report from ZEP meeting

We got an update on developments with CCS in Europe at the Brussels meeting in Sept 26 of the European Zero Emission Technology and Innovation Platform (ZEP).
By Karl Jeffery

Rotterdam has a new CCS project called Porthos; the EU has a new 'Innovation Fund' for climate related projects awarding carbon credits worth Eur 10bn; Norway's CCS projects are probably conditional on some EU support. These are some of the CCS developments we learned about at the Sept 26 Brussels meeting of the European Zero Emission Technology and Innovation Platform (ZEP), an organization formed by European utilities, petroleum companies, equipment suppliers, scientists, academics and environmental NGOs.

Delegates heard about the latest developments in Europe at the ZEP meeting in Brussels

There has been a growth in interest in large scale projects, said Luke Warren, chief executive of the Carbon Capture and Storage Association and representing the ZEP Secretariat. But the lack of progress is due to the "inability to develop a commercial business model."

Mr Warren emphasised that the "really detailed work" by the Intergovernmental Panel on Climate Change (IPCC), about different pathways to climate stabilisation, shows that 95 per cent of the pathways "require CCUS at scale".

Christian Holzleitner, European Commission

Christian Holzleitner, Head of Unit, Land Use and Finance for Innovation, DG Clima, said the EU is setting up a new "Innovation Fund," to support the development of new technology and business models for climate action over the long term (up to 2050).

DG Clima is a European Commission department responsible for EU policy on climate action. It leads international climate negotiations for the EU.

The EU's Innovation fund will distribute free rights to emit CO_2 to the chosen companies, with plans to distribute over 450m tonnes of CO_2 allowances, worth over Eur 10bn at today's carbon price of Eur 20 to 22. It aims to include energy intensive industries.

The Innovation Fund project team also plans to be more flexible in how the rewards are distributed, than with EU climate innovation funds in the past, where often money was only paid once a project was in operation. Now it will fund projects at the inception stage, thus helping projects get started if they are not self-funding.

DG Clima also wants to select projects with innovative business models and breakthrough technologies, not just least cost solutions, he said.

"We are looking for mature projects and a business case."

The Innovation Fund should "be a laboratory of what a new business model will look like, how should a future market look like, how best to plant the seed for a future market." he said.

It should also look at how to handle the challenge of regulations moving emissions to the "non ETS sector", industries not directly affected by ETS regulations (such as from plants outside Europe).

The first call for projects is planned for 2020.

The Paris agreement sets the "key context" for the climate discussion in government, he said. Despite the withdrawal of the US, it is "one of the most successful international agreements", he said, setting the core objectives.

The Paris agreement defines what will happen in a 'top down' way – but it also encourages 'bottom up' activity, encouraging partners to come up with plans and actions.

Under the Paris agreement, all parties should submit long term strategies by 2020, with the period up to 2050-2100.

DG Clima is working on the long term plan for Europe, with a plan to lay out the first vision for how it will cut emissions at the November 2018 UN Climate Change conference in Poland.

Within the EU, CO_2 emissions have reduced by 25 per cent since 1990 while the economy "doubled", so the 2020 targets should be "overachieved", he said. Meanwhile we have seen big cost decreases in renewable energy, and new developments covering transport, housing and forestry.

If electric cars are cost competitive with combustion engine cars by 2025, as some analysts predict, “that changes discussions a lot,” he said, with a pathway to gradual electrification of the whole economy.

Other developments can include zero carbon hydrogen power for industry, such as steel making. There could also be biofuels as feedstocks to chemical processes.

“Climate action can turn into a business opportunity. Consumers like climate friendly products, less pollution and noise,” he said.

Currently the European Union gives about 3-4 per cent of its GDP to Russia and Saudi Arabia to buy hydrocarbons. Instead “we can spend in Europe,” he said.

The EU is not looking for a silver bullet on climate, he emphasised. It wants to “lay out” the different pathways and measures which can be taken to reduce CO2.

Norway

Bjørn Haugstad, General Director, the Ministry of Petroleum and Energy, Climate, Industry and Technology Department, Norway, said that Norway’s carbon capture project, collecting a waste incinerator and a cement manufacturer to a CO2 storage is “on track”.

Companies involved include cement manufacturer Norcem (a subsidiary of cement giant Heidelberg; Fortum, an operator of a waste incinerator in Oslo; and oil companies Equinor, Shell and Total, looking at the CO2 transport and storage. Both Norcem and Fortum are planning to sequester 400,000 tonnes of CO2 per year.

The final funding decision is planned for 2020 – 2021. But there are many challenges in getting there, which are “all showstoppers”, he said.

The toughest challenge will be money, with an estimated cost of Eur 1.6bn for running the 2 capture sites, transport and storage for 5 years, or Eur 3000 for each resident of Norway. “It is probably too expensive for Norway to finance completely,” he said.

So Norway is exploring possibilities to receive funding from other member states and the European Commission.

But a problem is that the timing of the next round of the EU’s Innovation Fund does not align, with a call for proposals scheduled for 2020, and rewards in 2022, while Norway wants to make a decision about whether to move forward in 2020.

“We depend on European support, administratively, economically and politically,” he said. “Good luck to all of us”.

Another issue is cross border CO2 transport is currently not allowed under the London Convention of 1972 “The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter”. For CO2 to be delivered from the UK and Netherlands to Norway’s storage site, the Conventional will need to be amended. So far the amendments have only been ratified by

Finland, Netherlands, UK, Iran and Norway.

The Norwegian government will be looking to ensure that the projects “make a significant contribution to adoption of CCS in Europe.”

The big picture is that any two out of three out of “energy affordability, security, low emissions” are achievable. But “all three are still beyond reach,” he said.

Norway currently uses renewables for 97 per cent of its power and heating (mainly hydroelectricity), and is a “pioneer in CO2 taxation”, charging companies several times as much as the current ETS price if they want to emit CO2, he said.

Trude Sundset, CEO of Gassnova, an organisation which runs CCS projects for the Norwegian state, said she would be very keen for the storage site to take CO2 from the UK, which could be carried by ship. It works out about the same distance from parts of the UK coast to the storage site, as it is from Eastern Norway (where the cement and waste incinerator are) to the storage site.

The Norwegian government accepts responsibility for the risks of CO2 transport and storage, which is important, because it would be hard for a private company to accept the risks on a new project.

After the talks, Chris Davies, a former MEP and “rapporteur” for carbon capture

In the Q+A session, Chris Davies, a former MEP who did a great deal of work to encourage CCS discussions in Brussels from 2008 to 2014, said he thought the major issue was the “lack of urgency”. The lack of progress since discussions began in 2008 means “we’ve lost an entire decade”, he said.

“We hear it may be 2022 before [Innovation] awards are declared. You’ll have all the information you need by 2020. We don’t need all these obstacles,” he said.

The EU’s Christian Holzleitner noted that one cause of failure for previous climate projects under the NER300 scheme was that projects was a lack of “sufficiently mature” projects. There were projects selected in 2012 which were not ready to operate 3-4 years later.

Rotterdam

The Port of Rotterdam is planning a new carbon capture project with a 30km onshore CO2 pipeline along the Port of Rotterdam, connecting together several large CO2 emitters, running to the beach.

There will be an onshore compressor, and then send the CO2 offshore, to a storage site, such as a depleted gas field. The CO2 can also be taken to greenhouses where it can be used as a fertiliser.

The project is led by Tim Bertels, formerly head of CCS with Shell (until December 2016), now running his own consultancy.

The project is designed to handle 10mt CO2 a year, perhaps through a second phase where it connects with other big CO2 emitters in the region, including in Zeeland (South West Netherlands), Antwerp and Chemelot Chemical Park. But just building a project to handle 2-4 mtpa is “tough enough,” Mr Bertels said.

The project is planned with a lifetime of 10-15 years. It has 40-60 people involved in various part time and full time roles.

At current carbon prices, the whole project has a “negative business case” – i.e. will cost more to run than it will make. So it will need funding from public authorities.

The “real innovation” in the idea is for it to have multiple hubs connected to a single backbone, he said. “That requires engineering and commercial thinking.”

Getting it moving may require more sense of urgency from government, he said. It will need millions of Euros on pre-FEED [front-end engineering and design], tens of millions on

FEED, hundreds of millions on CAPEX".

In theory, it should have a strong supporter in the Dutch government, which plans a 49 per cent reduction in its CO2 emissions by 2030, targeting [heavy] industry, electricity, mobility, agriculture and the built environment.

Once carbon capture and storage is in place, it could open the door to other developments, such as reinvesting in refineries, generating hydrogen, getting heat from electricity, and making synthetic fuels, he said.

Based on his experience working on Shell's "Quest" CCS project in Canada, a close collaboration with governments, particularly on permits and funding, is very critical in making the projects work.

An economist's view

Karen Turner, Director of the Centre for Energy Policy, University of Strathclyde, talked about the wider economic implications of CCS – both if it is used and if it is not used.

The oil and gas industry feeds wider demand and money into a country's economy – for example the UK estimates that ten jobs are created in the wider economy for one oil and gas job. So if carbon capture and create jobs in the oil and gas industry, or conversely send oil and gas production out of the UK, there is a wide impact.

Similarly, if climate regulation just means that cement manufacture is shifted from for example Germany to Turkey or China, then the overall loss to Germany will be more than the jobs in the cement manufacturing itself.

Also if a German cement plant would have been more efficient than the one in (for example) China, that may mean that there is a net increase in CO2 emission. So just regulating CO2 from cement plants could mean increased CO2 and much broader job losses.

Ms Turner noted that climate is not a top priority for many people – they care about it, but not as much as they care about keeping their jobs.

What has changed

The panel was asked what they think has changed the most in carbon capture over the past 5 years.

Trude Sundset, CEO, Gassnova said that one change has been the shift in focus from CCS on coal power plants to CCS on industry. Also the Paris agreement has "changed the narrative for CCS".

Perhaps a past error has been to be too focussed on technology itself, not the "challenges we are solving with technology," she said.

Tim Bertels agreed that the Paris goals have changed things, with companies feeling increased pressure to start "doing something". We can see the goals are slowly turning into concrete plans. Also the slow rise in the ETS price is helpful, he said. There is also a growing realisation in the Netherlands that managing CO2 emissions is not just about renewables.

Competition

The panel was asked whether the Norway and Netherlands projects are effectively in competition for EU funding.

Gassnova's Trude Sundset noted that the world needs "hundreds of thousands of these projects", so should not look at the two projects as being in competition. And also there is the option that the Netherlands project could ship its CO2 to Norway's storage site, rather than invest in its own CO2 storage, she said.

Rotterdam's Tim Bertels said he had a plea that both of the projects will be a success. "We can't afford another failure. This is the 3rd round of CCS in Europe," he said.

CCS policy

"We've got a strong view we're not moving faster enough [on CCS]," said Graham Bennett, Vice President, DNV GL.

"The reality is, there isn't enough steel going into the ground".

DNV GL's current forecasts show a 2.6 degrees increase in temperature by the end of 2100, and a total of 972 gigatonnes of CO2 emission up to 2050.

To meet the "carbon budget", keeping temperature rise under 2 degrees, requires reducing this to 810 gigatonnes.

DNV GL forecasts worldwide emissions of 34 gigatonnes per year by the world at its peak, which should be reduced to 18 gt by 2050.

Benedikt Unger, Senior Consultant, Pöyry, a consultancy specialising in capital intensive industries, said that if we're going to decarbonise 95 per cent by 2050, that means some sectors, including energy, need to decarbonise completely. There are some industry sectors where greenhouse gas emission is nearly impossible to avoid, such as agriculture.

This further emphasises the need to decarbonise cement, since the only alternative, if the 95 per cent cut is reached, would be to decarbonise everything other than cement, with cement producing about 5 per cent of all emissions, he said.

According to Pöyry's model, decarbonisation could be achieved with "almost no energy storage necessary", because electric transport and heating offer scope for flexibility, the ability to reduce demand when it is particularly high.

Pöyry's model has looked at consumption patterns for every hour of the year, through different weather patterns, including particularly unusual years.

The 2040 decarbonisation target can be reached all with renewables and efficient gas turbine power, he said. CCS will be need for further decarbonisation beyond that, he said.

Joseph Yao, Research Associate with the Department of Chemical Engineering, Imperial College London, noted that if the aim is to decarbonise without CCS, that will mean a lot of underutilised renewables, which are just standing available to meet peak demand.

He also noted that the value of wind power has been seen to decline with the amount of deployment – so there is a level of wind power above which investors get declining returns.

Bellona

A panel debate was held on "negative emissions", where biofuels are combusted and the CO2 stored. This means a net removal of CO2 from the atmosphere, since the plants absorb CO2 as they grow, and the CO2 ends up in the ground.

Such negative emissions are necessary in order to meet the toughest CO2 targets, such as limiting temperature change to 1.5 degrees, which would basically mean that all the CO2 being emitted from today onwards would eventually need to be captured and sequestered, said Frederic Hauge, Founder and President, Bellona.

All the other methods of capturing Co2 from the air are much more expensive than biomass with CCS.

Along with this, should go better ways to produce biomass faster without affecting other land use and water supplies – such as growing biomass in seawater, he said. Bellona has "started a company to grow seaweed with large scale potential."

Another idea is to use solar power to pump water from the sea to enable onshore agriculture in dry areas. Pumping water horizontally uses a lot less power then pumping it vertically.

Biomass + CCS could also combust some of the large amounts of biowaste, with large amounts being generated particularly in Romania and Poland, he said.

Biofuel for automotive is probably a worse environmental option than battery power, he said.

Bellona estimates that the cost of decarbonising without CCS works out at 2-4 trillion euros more expensive than decarbonising with CCS – a number which ought to be large enough to create business opportunities somewhere.

Mr Hauge noted that while the interest from industry in carbon capture is good, the need remains to do carbon capture for power generation, which provides 81 per cent of emissions. Perhaps not in Europe, where "renewables are coming in fast".

More information

Download the presentations at:

www.zeroemissionsplatform.eu

UKCCSRC meeting - supporting CCUS implementation through innovation

The UKCCSRC autumn conference reviewed the UK Cost Challenge Task Force (CCTF) report to to assess where UKCCSRC members and associates can contribute to delivering its aspirations and highlighted the latest research.

Delegates discussed the CCS opportunity for the UK, implementing CCUS through a cluster approach and developing a pipeline of financeable projects.

After lunch the delegates split into themed groups to discuss priority research directions and come up with recommendations. These themes and some key points were:

Storage and Gas Power

It is likely that gas fired power plants will be part of the future's energy mix, which will be penetrated by renewables. Therefore, gas-CCS will be operated flexibly and the associated capture plant will need to adjust to new boundary conditions. Realising cost effective operating strategies such as minimising the capture rate during peak demand hours and increasing the capture rate at times with lower demand could lead to an overall lower costs of capture.

Social

The group discussed the need to identify the right stakeholders for any social research. It also touched on the increasing role of social media in shaping public opinion and the need to exploit such channels through proper social research in the context of CCS

Utilisation

The group discussed why compared to capture and storage, utilisation seems to be going at a snail's pace. There were several suggestions including the lack of market, absence of a policy frame work, low awareness among the community, and uncertainty in investment. Obviously, cost is a factor when it comes to implementation at industrial scale.

Hydrogen

H2 production mainly comes from the steam reforming process (SRP) where natural gas is used as feedstock. The consensus was that improving CCUS systems incorporated in the SRP would contribute substantially in the transition for sustainable energy production with a CO2-neutral energy supply but in order to reach the 2°C scenario, the generation of electricity must be complemented with renewable sources such as wind and sun.

Steel Industry

CCS on a steel plant is going to add a huge increase in the production cost. Therefore, the market of "low-carbon products" is one option, but there is need for a market for these products and ultimately be able to pass costs to customers for low-carbon products.

BECCS

Increasing efficiency for biomass power plant is highly challenging, it is important to investigate different chemical and thermodynamic solutions to increase overall efficiency of power plant with low cost and less emissions.

Storage & Shipping Combinations

Attention was drawn to the need to understand the effect of CO2 on seals and materials of construction. This is because CO2 can mix with any water available to form corrosive carbonic acid. This brought up a discussion on impurities in captured CO2 and thermodynamic models to predict the CO2 mixture properties.

More information

See the full blogs on each session, slides and research posters:

www.ukccsrc.ac.uk

Projects and policy news

European Commission and Bill Gates launch €100 million clean energy investment fund

www.b-t.energy

Breakthrough Energy Europe is a joint investment fund to help innovative European companies develop and bring radically new clean energy technologies to the market.

Breakthrough Energy Europe links public funding with long-term risk capital so that clean energy research and innovation can be brought to market faster and more efficiently. With a capitalisation of €100 million, the fund will focus on reducing greenhouse gas emissions and promoting energy efficiency in the areas of electricity, transport, agriculture, manufacturing, and buildings. It isa pilot project that can serve as a model for similar initiatives in other thematic areas.

Breakthrough Energy Europe is expected to be operational in 2019. Half of the equity will come from Breakthrough Energy and the other half from InnovFin – risk-sharing financial instruments funded through Horizon 2020, the EU's current research and innovation programme.

President Jean-Claude Juncker said: "Europe must continue to take the lead in tackling climate change head on, at home and across the world. We must push for the modernisation of Europe's economy and industry in order to meet the ambitious targets put in place to protect our planet. Pooling public and private investment in new, innovative clean energy technology is key to enabling long-term solutions to reduce greenhouse gas emissions. If Europe is to have a future that can guarantee the well-being of all its citizens, it will need to be climate-friendly and sustainable."

Bill Gates, Chairman of Breakthrough Energy Ventures, said: "We need new technologies to avoid the worst impacts of climate change. Europe has demonstrated valuable leadership by making impressive investments in R&D. The scientists and entrepreneurs who are developing innovations to address climate change need capital to build companies that can deliver those innovations to the global market. Breakthrough Energy Europe is designed to provide that capital."

Oil and Gas Climate Initiative welcomes Chevron, ExxonMobil and Occidental Petroleum

oilandgasclimateinitiative.com

The addition of three US companies expands the OGCI's representation to around 30% of global oil and gas production.

The three new companies become official members on September 24, 2018 expanding the global reach and impact of OGCI.

With these additions, OGCI members now represent around 30% of global oil and gas production and supply close to 20% of global primary energy consumption. The 13 member companies represent regions including China, the Middle East, Latin America, Europe and now the United States, widening OGCI's global reach and making its members' collaborative effort in support of the Paris Agreement, a significant global action.

The new OGCI members are aligned with the OGCI collective goals, including recognition and support of the Paris Agreement and collective reporting; they will also reinforce the capacity of OGCI's work programs. In addition, each will commit $100 million dollars to the OGCI Climate Investments fund.

In a joint statement, the heads of the OGCI member companies said: "Over the past four years, OGCI has brought together international and national oil and gas companies to accelerate the deployment of concrete solutions to reduce greenhouse gas emissions. Our ambitions increase each year and as we welcome three new member companies, we will continue to build momentum and strengthen our collective reach and impact to deliver practical action on climate change."

"It will take the collective efforts of many in the energy industry and society to develop scalable, affordable solutions that will be needed to address the risks of climate change," said Darren Woods, Chairman and Chief Executive officer of ExxonMobil. "Our mission is to supply energy for modern life and improve living standards around the world while minimizing impacts on the environment. This dual challenge is one of the most important issues facing society and our company."

The OGCI will hold its annual meeting with stakeholders in New York next week during Climate Week.

CO2 Capture Project report on role of CCS in the energy transition

energy.mit.edu/lcec

The report provides current views and projections for the role of CO2 Capture and Storage (CCS) in the energy sector and what aspects need to be evaluated for CCS to play a significant role in the energy transition.

The report – Role of CCS in the Energy Transition – addresses four key questions:

• What impetus is created for CCS by the ambition to reduce global greenhouse gas emissions under the Paris Agreement?

• How is CCS treated in the leading scenarios and analyses related to the transition over time to a low-carbon energy mix?

• To what extent do government plans and policies serve to support the role of CCS in the energy transition (or downplay the role of CCS)?

• What sorts of actions could help CCS achieve its long-term potential to contribute to the energy transition and the Paris Agreement ambition?

One of the main conclusions is that the five leading energy transition scenarios reviewed in the report include CCS and favourably estimate its contribution to reaching a 2-degree world, giving CCS a sizeable role in emissions reductions. More specifically, the contribution of CCS to scenarios that could successfully achieve the Paris Agreement goals range from 10-25% of the total GHG emissions response effort depicted in those scenarios.

Mark Crombie, CCP4 Program Manager and BP's P&I member, comments: "The report evaluates in detail the current situation regarding the role of CCS in the energy transition. Looking ahead, the report points out that even if nations did not mention CCS in their nationally determined contributions or in a mid-century strategy, they should consider CCS as part of future actions."

Montana State researchers win $1.5 million for developing CO2 tech

A special ceramic slurry and a conveyor belt whose surface is minus 30 degrees are some of the things a Montana State University researcher will use to help turn carbon dioxide into useful products.

"It's materials science, but there's also an art to it," said Stephen Sofie, professor in the Department of Mechanical and Industrial Engineering.

In his lab recently, Sofie carefully poured the ceramic slurry onto the conveyor surface, where it spread into a thin sheet. As the conveyor moved very slowly over a powerful cold source, small ice crystals formed as the slurry hardened - a process called freeze-casting.

"It's casting really nicely," Sofie said. "It looks simple but there are a lot of details," including the precise mixing of several ingredients in the slurry and the rate at which it freezes.

Once the slurry solidified, Sofie placed it in a freeze-dryer that would remove all the water, leaving tiny pores where the ice crystals once were. The result, a membrane that can control chemical reactions by evenly distributing gases, is a technology that Sofie plans to refine in the coming months with a $1.5 million grant he received from the U.S. DOE.

According to Lee Spangler, director of MSU's Energy Research Institute and a co-principal investigator on the project, the freeze-casting method could provide the key to scaling up another technology that converts carbon dioxide to formic acid, a product commonly used as a food additive and in a variety of industrial processes.

The formic acid technology, called ECForm, works by applying electricity as carbon dioxide filters through a membrane. The company that developed the technology, OCO, has demonstrated the process with prototypes, according to OCO co-founder and president Terry Brix, a 1967 MSU chemical engineering alumnus. But scaling it up to the levels needed for industrial production requires membranes whose pore structure can be carefully controlled, he said. That's where Sofie's freeze-casting comes in.

Brix and his son, Todd Brix, CEO of the company, approached Spangler last spring because of MSU Energy Research Institute's work on carbon dioxide sequestration. "We recognized an opportunity," Spangler said. "We realized (OCO) was working on a technology that MSU could help improve." Shortly thereafter, Sofie and Spangler, with OCO's support, put together the Energy Department grant proposal.

MSU mechanical engineering professor Stephen Sofie demonstrates the freeze-casting process his MSU team will scale up and refine in order to make special membranes that could convert carbon dioxide into useful products. MSU Photo by Adrian Sanchez-Gonzalez

"We think this potential improvement could significantly reduce the cost (of ECForm)," Terry Brix said. "That would be a big deal in the chemical engineering world."

Chemists have long known how to convert carbon dioxide to formic acid, Terry Brix said, but the processes that have been developed to date aren't economically attractive to industry. That why most formic acid produced today is made from petroleum, he said.

Sofie's experience with freeze-casting dates back more than a decade, to graduate research in which he helped pioneer the technique, which is sometimes called ice templating. At NASA's Glenn Research Center, he used freeze-casting to develop membranes for fuel cells that could power spacecraft and modules for human habitation on the moon and Mars.

With the Energy Department funding, Sofie's team will explore ways to advance the technology by precisely controlling the spacing and structure of the pores. Sofie and Spangler hold a provisional patent on a process that involves varying the amounts of ceramic materials in the slurry as it is applied to the conveyor surface, Sofie said.

That could produce custom-made membranes up to 2 feet wide through which large volumes of carbon dioxide would flow in an optimal way for the ECForm process, Terry Brix said. That would reduce the electricity needs -- and therefore the cost -- of the formic acid reaction, he added.

According to Spangler, if ECForm can be scaled up economically, it would provide an incentive for producers of carbon dioxide -- such as coal-fired power plants -- to capture the gas and convert it to formic acid, which they could sell for a much higher price than raw carbon dioxide. The new freeze-casting technology could also lead to improved fuel cells, batteries and other products, he said.

Sofie is excited that freeze-casting the membranes is environmental friendly as well. "What's really outstanding with our methods is that they are water-based," he said. "There aren't any toxic solvents involved."

More information

www.montana.edu

Catalyst opens door to CO2 capture in conversion of coal to liquid fuels

Researchers from the National Institute of Clean-and-Low-Carbon Energy in Beijing and Eindhoven University of Technology have developed iron-based catalysts that substantially reduce operating costs and open the door to capturing large amounts of CO2 generated by CTL.

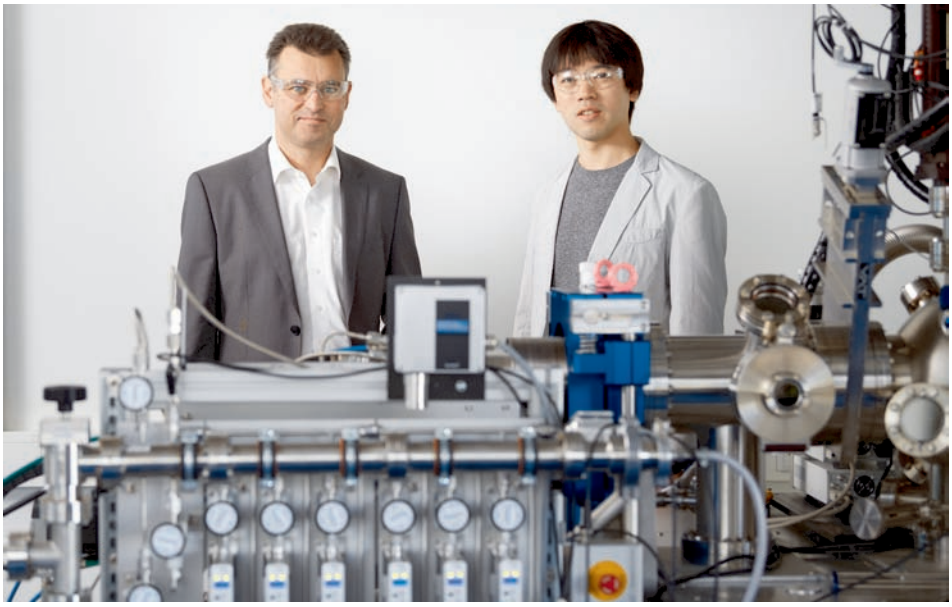
World energy consumption projections expect coal to stay one of the world's main energy sources in the coming decades, and a growing share of it will be used in CTL, the conversion of coal to liquid fuels.

To understand the significance of this achievement, some knowledge of the CTL process is required. The first stage is the conversion of coal to syngas, a mixture of carbon monoxide (CO) and hydrogen (H2). Using the so-called Fischer-Tropsch process, these components are converted to liquid fuels. But before that can be done, the composition of the syngas has to be changed to make sure the right products come out in the end - liquid fuels. So some of the CO is taken out of the syngas (rejected) by converting it to CO2, in a process called 'water-gas shift'.

In this chain the researchers tackled a key problem in the Fischer-Tropsch reactor. As in most chemical processing, catalysts are required to enable the reactions. CTL catalysts are mainly iron based. Unfortunately, they convert some 30 percent of the CO to unwanted CO2, a byproduct that in this stage is hard to capture and thereby often released in large volumes, consuming a lot of energy without benefit.

The Beijing and Eindhoven researchers discovered that the CO2 release is caused by the fact that the iron based catalysts are not pure, but consist of several components. They were able to produce a pure form of a specific iron carbide, called epsilon iron carbide, that has a very low CO2 selectivity. In other words, it generates almost no CO2 at all.

The existence was already known but until now it had not been stable enough for the harsh Fischer-Tropsch process. The Sino-Dutch research team has now shown that this instability is caused by impurities in the catalyst. The phase-pure epsilon iron carbide they developed is, by contrast, stable and remains functional, even under typical industrial processing conditions of 23 bar and 2500°C.



Researchers Emiel Hensen and Wei Chen have developed a new catalyst that eliminates nearly all CO2 generation in the Fischer-Tropsch reactor reducing the energy needed and the operating costs. Photo Bart van Overbeeke (TU/e)

The new catalyst eliminates nearly all CO2 generation in the Fischer-Tropsch reactor. This can reduce the energy needed and the operating costs by roughly 25 million euros per year for a typical CTL plant. The CO2 that was previously released in this stage can now be removed in the preceding water-gas shift stage. That is good news, because it is much easier to capture in this stage.

The conversion of coal to liquid fuels is especially relevant in coal-rich countries that have to import oil for their supply of liquid fuels, such as China and the US. "We are aware that our new technology facilitates the use of coal-derived fossil fuels. However, it is very likely that coal-rich countries will keep on exploiting their coal reserves in the decades ahead. We want to help them do this in the most sustainable way," says lead researcher professor Emiel Hensen of Eindhoven University of Technology.

The research results are likely to reduce the efforts to develop CTL catalysts based on cobalt. Cobalt based catalysts do not have the CO2 problem, but they are expensive and quickly becoming a scarce resource due to cobalt use in batteries, which account for half of the total cobalt consumption.

Hensen expects that the newly developed catalysts will also play an import role in the future energy and basic chemicals industry. The feedstock will not be coal or gas, but waste and biomass. Syngas will continue to be the central element, as it is also the intermediate product in the conversion of these new feedstocks.

The results are published in the journal Science Advances.

More information

www.tue.nl

MIT researchers develop carbon capturing battery

The new lithium-based battery could capture and store CO2 as a solid carbonate mineral.

A new type of battery developed by researchers at MIT could be made partly from carbon dioxide captured from power plants. Rather than attempting to convert carbon dioxide to specialized chemicals using metal catalysts, which is currently highly challenging, this battery could continuously convert carbon dioxide into a solid mineral carbonate as it discharges.

While still based on early-stage research and far from commercial deployment, the new battery formulation could open up new avenues for tailoring electrochemical carbon dioxide conversion reactions, which may ultimately help reduce the emission of the greenhouse gas to the atmosphere.

The battery is made from lithium metal, carbon, and an electrolyte that the researchers designed. The findings are described today in the journal Joule, in a paper by assistant professor of mechanical engineering Betar Gallant, doctoral student Aliza Khurram, and postdoc Mingfu He.

Currently, power plants equipped with carbon capture systems generally use up to 30 percent of the electricity they generate just to power the capture, release, and storage of carbon dioxide. Anything that can reduce the cost of that capture process, or that can result in an end product that has value, could significantly change the economics of such systems, the researchers say.

However, “carbon dioxide is not very reactive,” Gallant explains, so “trying to find new reaction pathways is important.” Generally, the only way to get carbon dioxide to exhibit significant activity under electrochemical conditions is with large energy inputs in the form of high voltages, which can be an expensive and inefficient process. Ideally, the gas would undergo reactions that produce something worthwhile, such as a useful chemical or a fuel. However, efforts at electrochemical conversion, usually conducted in water, remain hindered by high energy inputs and poor selectivity of the chemicals produced.

Gallant and her co-workers, whose expertise has to do with nonaqueous (not water-based) electrochemical reactions such as those that underlie lithium-based batteries, looked into whether carbon-dioxide-capture chemistry could be put to use to make carbon-dioxide-loaded electrolytes - one of the three essential parts of a battery - where the captured gas could then be used during the discharge of the battery to provide a power output.

This approach is different from releasing the carbon dioxide back to the gas phase for long-term storage, as is now used in carbon capture and sequestration, or CCS. That field generally looks at ways of capturing carbon dioxide from a power plant through a chemical absorption process and then either storing it in underground formations or chemically altering it into a fuel or a chemical feedstock.

Instead, this team developed a new approach that could potentially be used right in the power plant waste stream to make material for one of the main components of a battery.

While interest has grown recently in the development of lithium-carbon-dioxide batteries, which use the gas as a reactant during discharge, the low reactivity of carbon dioxide has typically required the use of metal catalysts. Not only are these expensive, but their function remains poorly understood, and reactions are difficult to control.

By incorporating the gas in a liquid state, however, Gallant and her co-workers found a way to achieve electrochemical carbon dioxide conversion using only a carbon electrode. The key is to preactivate the carbon dioxide by incorporating it into an amine solution.

“What we’ve shown for the first time is that this technique activates the carbon dioxide for more facile electrochemistry,” Gallant says. “These two chemistries - aqueous amines and nonaqueous battery electrolytes - are not normally used together, but we found that their combination imparts new and interesting behaviors that can increase the discharge voltage and allow for sustained conversion of CO2.”

They showed through a series of experiments that this approach does work, and can produce a lithium-carbon dioxide battery with voltage and capacity that are competitive with that of state-of-the-art lithium-gas batteries. Moreover, the amine acts as a molecular promoter that is not consumed in the reaction.

The key was developing the right electrolyte system, Khurram explains. In this initial proof-of-concept study, they decided to use a nonaqueous electrolyte because it would limit the available reaction pathways and therefore make it easier to characterize the reaction and determine its viability. The amine material they chose is currently used for CCS applications, but had not previously been applied to batteries.

This early system has not yet been optimized and will require further development, the researchers say. For one thing, the cycle life of the battery is limited to 10 charge-discharge cycles, so more research is needed to improve rechargeability and prevent degradation of the cell components. “Lithium-carbon dioxide batteries are years away” as a viable product, Gallant says, as this research covers just one of several needed advances to make them practical.

The researchers are also investigating the possibility of developing a continuous-operation version of the process, which would use a steady stream of carbon dioxide under pressure with the amine material, rather than a preloaded supply the material, thus allowing it to deliver a steady power output as long as the battery is supplied with carbon dioxide. Ultimately, they hope to make this into an integrated system that will carry out both the capture of carbon dioxide from a power plant’s emissions stream, and its conversion into an electrochemical material that could then be used in batteries. “It’s one way to sequester it as a useful product,” Gallant says.

More information

meche.mit.edu

Capture and utilisation news

Fluor to test its new capture technology at Mongstad

www.tcmda.com

www.fluor.com

Fluor wants to test a newly developed chemical solvent to separate carbon dioxide from industrial flue gases.

Fluor will use the Amine test plant at TCM, the world´s largest test facility for carbon capture, during the period Dec 2018 - May 2019.

Norway and the United States have a bilateral cooperation in the energy sector, including carbon capture. TCM is an important part of the venture. Relations between the countries were further strengthened in February when the US Department of Energy awarded USD 33.7 million to four US companies who aim to test their carbon capture technology projects at TCM.

Carbon capture has become the most important part of the energy collaboration between Norway and the United States. Fluor follows ION Engineering as the second US DoE funded company using TCM in a test campaign. It is positive for us that US authorities support major companies in their desire to test technologies at our facilities, says TCM's business development manager, Bjørn-Erik Haugan.

U.S. DOE announces $30 million for transformation CCS technologies

www.netl.doe.gov

Selected projects will support the development of solvent, sorbent, and membrane technologies to address scientific challenges and knowledge gaps associated with reducing the cost of carbon capture.

Up to $30 million in federal funding will be available for cost-shared research and development under the second closing of the Office of Fossil Energy's Novel and Enabling Carbon Capture Transformational Technologies funding opportunity announcement.

Specifically, projects must address one area of interest, Development of Novel Transformational Materials and Processes, with the following three subtopics:

Subtopic 1A: Novel Solvents for Lab-Scale R&D

Projects under this subtopic will support the development of high-performance capture systems via the design of new solvents and solvent mixtures with the necessary property combinations to lead to transformational technology development.

Subtopic 1B: Novel Sorbents for Lab-Scale R&D

Projects under this subtopic will support (1) development of tailor-made sorbent materials targeted to specific carbon capture applications and (2) development of specific sorbent materials that show enhanced long-term reactivity and recyclability and other properties.

Subtopic 1C: Novel Membranes for Lab-Scale R&D

Projects under this subtopic will seek to fill research gaps in either membrane transport properties or process designs. Research in transport properties should lead to new membrane materials with improved performance, while development of new process designs should reduce pressure drop and energy consumption.

Hybrid systems are also eligible for this FOA based on the three subtopic technology types capable of revolutionary step-change reductions in carbon dioxide (CO2) capture costs and energy penalties. Hybrid technologies proposed should be submitted to the most appropriate subtopic.

Using a cerium catalyst to capture CO2

www.rsc.org

A new catalyst could capture and transform carbon dioxide – creating useful chemicals from a greenhouse gas.

Carbon dioxide is perhaps the most notorious of the greenhouse gases – contributing to global warming and indirectly causing extreme weather, drought, famine, and the melting of the ice caps. There's no doubt that the vast quantities of carbon dioxide being pumped into the atmosphere by industrial activity, the burning of fossil fuels, and countless day-to-day activities are very harmful to the planet.

However Professor Polly Arnold from the University of Edinburgh points out that the gas also has lots of useful applications. "It could be used as a precursor to many valuable materials such as biorenewable solvents, plastics, and pharmaceuticals."

This means that if we could find a way to capture carbon dioxide and transform it into other types of molecules we could reduce the amount of the gas in the atmosphere, and produce useful chemicals in the process.

Professor Arnold's team have studied a series of compounds for carbon capture based on the element cerium, which is naturally abundant, relatively cheap, and has low toxicity. Cerium can act as a catalyst in a range of chemical reactions. The compounds also include tethered N-heterocyclic carbenes – a type of molecule that also has catalytic properties. Combining two catalysts in one has enabled the team to study and tune a great number of possible reactions.

Using this system, the team believe they will be able to capture and store carbon dioxide, before transforming it into a more useful chemical and releasing it. "Understanding the system has also allowed us to extend the reactivity to other molecules that are chemically similar to carbon dioxide", explains Prof. Arnold.

Professor Arnold explains why the team have focused on cerium compounds. "There is a huge push to move away from using the noble metals to make catalysts, but people have mainly studied the 1st row of the transition metals as their replacements. Although cerium is one of the 'rare earth' elements, this name is a misnomer."

"Cerium can be classed as earth-abundant, being more common than iodine, its chloride is about six times less toxic than that of iron, and it is a cheap by-product of the mining of technology critical rare earths such as neodymium. So we are keen to learn how to tame it and its other less-understood f-block neighbours, for sustainable chemical catalysis."

She points out that previous similar systems have required specialised, high pressure gas reactors, whereas this one works at atmospheric cheaper. "Ideally, the perfect system is cheap, energy limited, and can be used off-the-rack", she says. "We are really excited to see how this project unfolds."

Transport and storage news

U.S. carbon capture network could double global CO2 headed underground

www.princeton.edu

With the right public infrastructure investment, the United States could as much as double the amount of carbon dioxide emissions currently captured and stored worldwide within the next six years, according to an analysis by Princeton University researchers.

The authors propose in the Proceedings of the National Academy of Sciences a pipeline network that would transfer carbon dioxide waste from ethanol refineries in the American Midwest - where grains are fermented to produce the alcohol-based fuel - to oil fields in West Texas. The captured carbon would then be pumped into near-depleted oil fields through a technique known as enhanced oil recovery, where the carbon dioxide helps recover residual oil while ultimately being trapped underground.

The researchers found that this capture-and-storage network could prevent up to 30 million metric tons of human-made carbon dioxide from entering the atmosphere each year - an amount equal to removing 6.5 million cars from the road. Currently, about 31 million metric tons of carbon dioxide annually are captured and stored worldwide.

The authors were motivated by a tax credit passed by Congress in the 2018 Bipartisan Budget Act to encourage investment in CCS. Their analysis showed that this large-scale capture-and-storage network would only be possible - and profitable for the companies using it - if the tax credits are coupled with low-interest government loans to fund the necessary pipeline infrastructure. If governments provided low-cost loans for only half of the pipelines, the resulting smaller-scale network would still sequester 19 million metric tons of CO2 per year.

"The new tax credits are the most significant policy incentivizing carbon capture, utilization and storage (CCUS) in the world today," said first author Ryan Edwards, a AAAS Congressional Science and Engineering Fellow in Washington, D.C., who earned his Ph.D. in civil and environmental engineering from Princeton this year. Edwards worked on the analysis as a graduate student under co-author Michael Celia, director of the Princeton Environmental Institute (PEI) and the Theodora Shelton Pitney Professor of Environmental Studies and professor of civil and environmental engineering.

"This is the first time we've had a policy in front of us that lets us seriously consider deployment on a large scale," Edwards said. "There's a lot of interest in CCUS at different levels, and bipartisan support. What there hasn't been is a plan for how this could happen and what it would look like."

Implementation of carbon storage infrastructure has been hamstrung by a lack of policy support and large upfront costs for individual projects, Celia said.

"In order for CCUS to have any chance for large-scale development, the necessary infrastructure needs to be built," Celia said. "This includes pipelines to transport CO2 from the locations where it is captured to the locations where it can be used. Our study provides an economically feasible roadmap to build such a pipeline, which would be a critical first step for large-scale CCUS in the United States."

Similar large-scale infrastructures such as the Interstate Highway System and electric-power grids have been built with government financing and coordination, Edwards said.

"Our analysis shows that additional public support beyond the tax credits will be necessary to enable large-scale deployment in the near-term," Edwards said. "That's how these things are done - governments play a key role. An excellent recent example is the leadership on clean-energy infrastructure by the Texas state government that enabled the big wind-energy boom there."

Edwards and Celia focused on ethanol refineries because the gas they produce is more than 99 percent carbon dioxide, which makes it among the most cost-effective to capture, Edwards said. By contrast, he said, the byproduct of burning coal is only 10-15 percent carbon dioxide and the capture technology is expensive. The cost of capturing carbon dioxide from coal or gas sources ranges from \$50-75 per metric ton, compared to around \$20-30 per metric ton for ethanol sources.

At the same time, Midwestern ethanol refineries — which produce 43 million metric tons of carbon dioxide annually — are located far from existing carbon dioxide pipelines and don't sit atop geological formations suitable for storing the gas, Edwards and Celia wrote.

Conventional recovery from an oil well yields about 40 percent of the total oil within the rock, Edwards said. Injecting carbon dioxide into the reservoir enables recovery of more oil, typically around an additional 15 percent, he said. The carbon dioxide is separated from the oil at the surface, then the gas is returned into the ground and ultimately trapped there.

The network Edwards and Celia propose could increase enhanced oil recovery in the United States — currently limited by a lack of affordable carbon dioxide — by 50 percent, they wrote.

"This can be a win-win for climate and domestic energy security," Edwards said.

"Global oil demand is expected to continue past 2050, so there is a need for new oil production," he said. "If there has to be more oil, it's much better environmentally that we produce oil domestically from an existing field rather than drilling new wells in places such as the Arctic, or importing it from new frontiers. Being able to also sequester captured carbon makes the overall technology extremely attractive."

The proposed network would still prevent far more carbon dioxide emissions than the oil it helps extract would produce, Celia said.

"The scale of the carbon problem is so large that no single technology can solve it," Celia said. "Fossil fuels are likely to be a significant energy source for the foreseeable future. CCUS is the only currently available technology that can solve the carbon problem while still allowing fossil fuels to be used. All current projections of a low-carbon energy future include significant amounts of CCUS."

The paper, "Infrastructure to enable deployment of carbon capture, utilization, and storage in the United States," was published Sept. 18 in the Proceedings of the National Academy of Sciences. This work was supported by the Princeton Environmental Institute (PEI) through the Carbon Mitigation Initiative, the PEI-Program in Science, Technology and Environmental Policy (PEI-STEP) Graduate Fellowship; and a 2017 Maeder Graduate Fellowship in Energy and the Environment from Princeton's Andlinger Center for Energy and the Environment.