Carbon Capture Journal

CCUS in the UK

CCSA London forum – CCS ready for investment?

Hydrogen: enabling the UK to reach net-zero emissions

Urgent action needed to progress UK CCUS

Jan / Feb 2020

Issue 73

CO_2 capture could be big business: up to 10 gigatonnes CO_2 a year could be stored according to study

Capturing carbon dioxide and turning it into commercial products, such as fuels or construction materials, could become a new global industry, according to a study by researchers from UCLA, the University of Oxford and five other institutions, published in Nature.

The research is the most comprehensive study to date investigating the potential future scale and cost of 10 different ways to use carbon dioxide, including in fuels and chemicals, plastics, building materials, soil management and forestry.

The study considered processes using carbon dioxide captured from waste gases that are produced by burning fossil fuels or from the atmosphere by an industrial process.

And in a step beyond most previous research on the subject, the authors also considered processes that use carbon dioxide captured biologically by photosynthesis.

The research found that on average each utilization pathway could use around 0.5 gigatonnes of carbon dioxide per year that would otherwise escape into the atmosphere. (A tonne, or metric ton, is equivalent to 1,000 kilograms, and a gigatonne is 1 billion tonnes, or about 1.1 billion U.S. tons.)

A top-end scenario could see more than 10 gigatonnes of carbon dioxide a year used, at a theoretical cost of under $100 per tonne of carbon dioxide. The researchers noted, however, that the potential scales and costs of using carbon dioxide varied substantially across sectors.

"The analysis we presented makes clear that carbon dioxide utilization can be part of the solution to combat climate change, but only if those with the power to make decisions at every level of government and finance commit to changing policies and providing market incentives across multiple sectors," said Emily Carter, a distinguished professor of chemical and biomolecular engineering at the UCLA Samueli School of Engineering and a co-author of the paper.

"The urgency is huge and we have little time left to effect change."

According to the Intergovernmental Panel on Climate Change, keeping global warming to 1.5 degrees Celsius over the rest of the 21st century will require the removal of carbon dioxide from the atmosphere on the order of 100 to 1,000 gigatonnes of carbon dioxide. Currently, fossil carbon dioxide emissions are increasing by over 1% annually, reaching a record high of 37 gigatonnes of carbon dioxide in 2018.

"Greenhouse gas removal is essential to achieve net zero carbon emissions and stabilise the climate," said Cameron Hepburn, one of the study's lead authors, director of Oxford's Smith School of Enterprise and Environment. "We haven't reduced our emissions fast enough, so now we also need to start pulling carbon dioxide out of the atmosphere. Governments and corporations are moving on this, but not quickly enough.

"The promise of carbon dioxide utilization is that it could act as an incentive for carbon dioxide removal and could reduce emissions by displacing fossil fuels."

Critical to the success of these new technologies as mitigation strategies will be a careful analysis of their overall impact on the climate. Some are likely to be adopted quickly simply because of their attractive business models.

For example, in certain kinds of plastic production, using carbon dioxide as a feedstock is a more profitable and environmentally cleaner production process than using conventional hydrocarbons, and it can displace up to three times as much carbon dioxide as it uses.

Biological uses might also present opportunities to reap co-benefits. In other areas, utilization could provide a "better choice" alternative during the global decarbonization process. One example might be the use of fuels derived from carbon dioxide, which could find a role in sectors that are harder to decarbonize, such as aviation.

The authors stressed that there is no "magic bullet" approach.

"I would start by incentivizing the most obvious solutions — most of which already exist — that can act at the gigatonne scale in agriculture, forestry and construction," said Carter, who also is UCLA's executive vice chancellor and provost, and the Gerhard R. Andlinger Professor in Energy and Environment Emeritus at Princeton University.

"At the same time, I would aggressively invest in R&D across academia, industry and government labs — much more so than is being done in the U.S., especially compared to China — in higher-tech solutions to capture and convert carbon dioxide to useful products that can be developed alongside solutions that already exist in agriculture, forestry and construction."

In addition to the researchers from UCLA and Oxford, the study's other authors are from the Mercator Research Institute on Global Commons and Climate Change in Berlin, Humboldt University in Berlin, Imperial College London's Centre for Environmental Policy, University of Leeds' School of Earth and Environment, and the Institute of Biological and Environmental Sciences at the University of Aberdeen in Scotland.

More information

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Back cover:
The "CATO Meets the Projects 2019" forum in Utrecht on November 26 showed big strides with CCS in the Netherlands
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Leaders - Review of 2019 and CCUS in the UK

Projects and policy

Capture and utilisation

Transport and storage

Global Status of CCS shows growing momentum but urgent action needed

The Global CCS Institute's flagship report launched at the UN climate change conference COP25 finds that the deployment of CCS has continued to gather pace, with the pipeline of CCS projects continuing to grow the second year in a row, up 37 per cent since 2017.

"Global Status of CCS 2019 Report: Targeting Climate Change" finds there are now 51 large-scale CCS facilities in operation or under development globally in a variety of industries and sectors. These include 19 facilities in operation, four under construction, and 28 in various stages of development. Of all the facilities in operation, 17 are in the industrial sector, and two are power projects.

"This has been one of the worst years on record for climate," said Global CCS Institute CEO Brad Page. "The clock is ticking, the world must act. Global emissions continue to rise, and climate impacts are expected to increase and have very dangerous implications. Bold climate action is needed to keep global warming to 1.5°C. CCS needs to be part of the climate solutions toolbox to tackle this challenge head on".

The United States is currently leading the way in CCS development and deployment with 24 large-scale facilities, followed by 12 facilities both in Europe and the Asia Pacific region, and three in the Middle East.

"Despite this increased momentum and progress in CCS deployment, the number of facilities needs to increase 100-fold by 2040, and scaling efforts are just not happening fast enough", warns Mr. Page. "Now is the time to rally for greater policy support and for capital to be allocated to build on the positive CCS progress of the past two years", Mr. Page adds.

Speaking at the report launch at COP25 in Madrid, Dr Julio Friedmann, Senior Research Scholar at the Center for Global Energy Policy at Columbia University, said: "The urgency of climate change and the harsh arithmetic of emissions demand CCUS deployment without delay. Policies that provide clean and durable alignment with markets and support continued innovation, especially expansion into new applications like heavy industry, hydrogen, and CO2

The need for and benefit from urgent action

The IEA's World Energy Outlook 2019 describes the measures necessary to deliver its Sustainable Development Scenario (SDS), a future where the United Nations energy related sustainable development goals for emissions, energy access and air quality are met. This scenario is consistent with a 66 per cent probability of limiting global temperature rise to 1.8 degrees Celsius without relying on large scale negative emissions. Under this scenario:

• Carbon capture utilisation and storage (CCUS)i provides 9 per cent of the cumulative emissions reduction between now and 2050

• The average mass of CO2 captured and permanently stored each year between 2019 and 2050 is 1.5 billion tonnes per annum

• The mass of CO2 captured and permanently stored in 2050 reaches 2.8 billion tonnes per annum

• The mass of CO2 captured is split almost equally between the power sector and industry sectors including iron and steel production, cement production, refineries and upstream oil and gas production.

The deployment of CCS is not happening quickly enough for it to play its role in meeting emissions reductions targets at the lowest possible cost. The IEA's 'Tracking Clean Energy' progress indicator, provides a status snapshot of 39 critical energy technologies needed to meet a less than 2°C target under its Sustainable Development Scenario (SDS). Only seven of the technologies assessed are "on-track". Critically CCS in power, and in industry and transformation, are "off-track".

To achieve the levels outlined in the SDS, the number of industrial scale facilities needs to increase a hundredfold, from 19 in operation now to more than 2,000 by 2040. To rapidly scale up the technology in a smooth and steady way, urgent action is required. Governments have a pivotal role to play, by providing a clear, stable and supportive policy framework for CCS.

The good news is that CCS provides a wealth of benefits in addition to its primary role in reducing emissions. It enables a just transition to new low emissions industries for communities currently reliant on emissions intense employment. It can protect people from the severe economic and social disruption that otherwise results from closing local industries. On top of this, CCS:

• supports high paying jobs;

• reduces total system costs of electricity supply by providing reliable, dispatchable generation capacity when fitted on flexible fossil fuel power plants;

• can utilise existing infrastructure that would otherwise be decommissioned, helping to defer shut-down costs;

• provides knowledge spillovers that can support innovation based economic growth.

The time available to limit temperature rises to 1.5°C is running out. Widespread use of CCS technology is critical to meeting these goals. We need to scale up deployment now.

removal, will make or break our future.”

The report shines light on the next wave of CCS projects globally, while also highlighting the flexibility, applicability and increasingly positive economics of applying CCS to a range of emission sources. The next wave of projects is expected to focus on large-scale abatement, through development of hubs and clusters. These capture CO2 from multiple industrial installations and use shared infrastructure for the subsequent CO2 transportation and storage to drive down costs.

Commenting on the report, Grantham Institute Chair, Lord Nicholas Stern, said, “We need to change the way we think about climate change as a global challenge, and start to regard it as an opportunity for innovation and growth. Against this backdrop, CCS becomes an ever more vital part of the process for reaching net-zero emissions”.

At the same time, hydrogen is also receiving policy attention not seen for decades around the globe. CCS, as a means to produce clean hydrogen on a large-scale, has gained momentum as part of this renewed interest in hydrogen as a clean energy vector of the future.

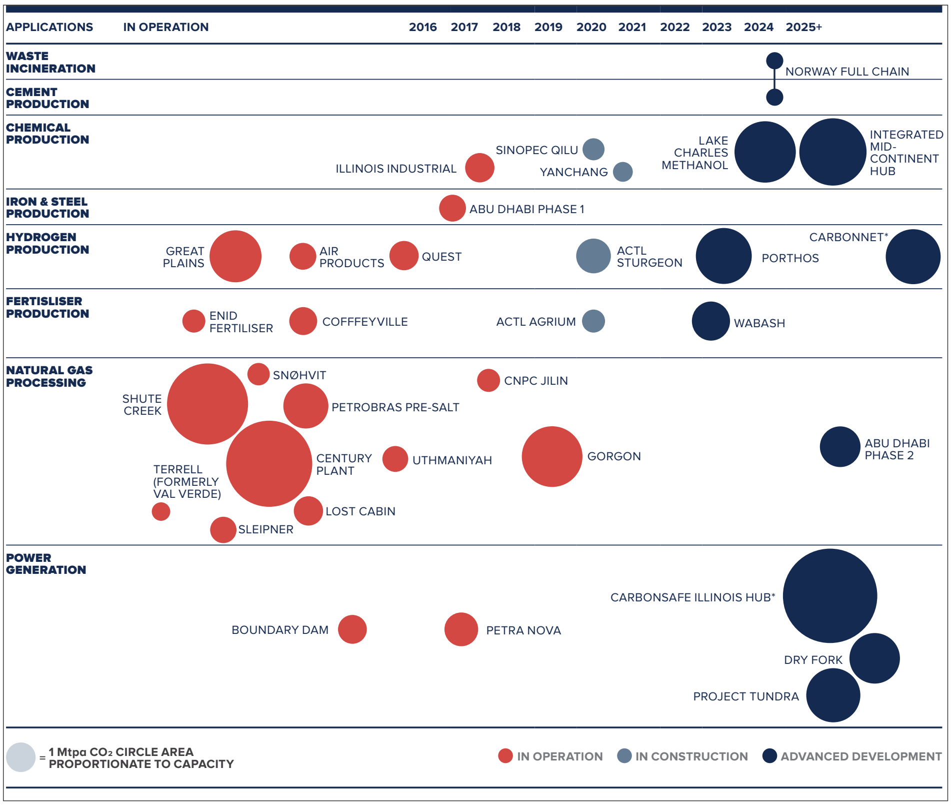
“Perhaps the most compelling development in the last 12 months though is that increasingly, CCS is a stand-out technology to genuinely deliver a just transition for many fossil fuel-based communities,” said Mr. Page.

The report features commentary and contributions from a wide range of leaders and influencers who draw on their expertise from across climate change, energy, academia, polar exploration, finance and CCS in voicing their support for the technology.

Next wave of CCS hubs and clusters

“Next wave” facilities based around CCS hubs and clusters have featured in 2019. Added to the Global CCS Institute's database in 2016, these facilities take advantage of the fact that many emissions intensive facilities (both power and industrial) tend to be concentrated in the same areas.

Hubs and clusters significantly reduce the unit cost of CO2 storage through economies of scale, and offer commercial synergies that reduce the risk of investment. They can play a strategically important role in climate change mitigation.



Power and industrial applications of large-scale CCS facilities in operation, under construction and in advanced development (Size of the circle is proportional to the capture capacity of the facility). Source: Global Status of CCS 2019

The way CCS projects are planned in Europe has changed considerably during the last decade. The focus used to be on building full chain solutions where one source of emissions would build their own transportation pipeline to their storage site. Now, most projects are planned as hubs and clusters.

Capturing CO2 from clusters of industrial installations, instead of single sources, and using shared infrastructure for the subsequent CO2 transportation and storage network, will drive down unit costs across the CCS value chain. Keeping a network open for third party CO2 deliveries, increases economies of scale.

Using a mix of transportation including pipelines and ships – but also trains and trucks – offers flexibility and accessibility to a wider range of CO2 sources around the industrial clusters. Several major industrial regions are planning CCS cluster development:

• Netherlands – Port of Rotterdam and Port of Amsterdam

• Belgium – Port of Antwerp

• UK – Humber and Teesside.

The Ruhr industrial cluster in Germany is expected to benefit from the CCS projects developed across the border in the Netherlands. A dedicated multi-partner ALIGN-CCUS project aims to contribute to the transformation of six European industrial regions into economically robust, low-carbon centres by 2025.

The project will create blueprints for developing low-emission industry clusters through CCUS and assess commercial models for CO2 cluster developments, including public-private partnerships.

The regulatory barrier of non-pipeline CO2 transport under EU ETS will need to be addressed in the next couple of years for Europe to fully benefit from the economies of scale offered by hubs and clusters. The legislation as it currently stands poses a regulatory barrier to those projects that wish to transport CO2 through different means (e.g. trains and barges).

More information

Download the full report:

www.globalccsinstitute.com

CCSA London forum – CCS ready for investment?

The Carbon Capture and Storage Association held a London forum on November 6 called "Capturing the Clean Growth Opportunities" – showing how UK CCS is on a path towards investability. By Karl Jeffery.

Chris Stark, chief executive of the Committee on Climate Change (CCC), says he believes "capital is available" which could be invested in carbon capture and storage, but it does need regulatory changes to make the investment case work. It would make sense for oil and gas companies to engage in it, he believes.

He was speaking at the Carbon Capture and Storage Association (CCSA) forum in London on November 6, "Capturing the Clean Growth Opportunities".

CCC is an independent authority on climate change established by the government, which provides advice to government entities. Mr Stark had "just come from a meeting with the Bank of England," which was interested in the risks, he said.

Mr Stark believes "the story on CCS is more exciting" when you include CO2 emissions from industry (rather than just power), and talk about hydrogen becoming a carrier fuel, made from gas with its carbon sequestered.

The conference, hosted by the Carbon Capture and Storage Association (CCSA), brought together nearly 200 people from the CCUS sector, including industry providers, potential customers, policymakers, investors and researchers (All images courtesy of CCSA)

"I'm a bit dubious about the U [utilisation]" he said. "But the CCS bit is absolutely essential."

In the UK, CCS is going through something of a "purple patch" (run of success) and "we have to capitalise on that," he said.

It is interesting to reflect on how fast people have accepted the idea about 'net zero'. When the UK government announced plans to become net zero in May 2019, "it was seen as an extreme position".

But by the time of the conference, in November 2019, a month before the UK's general election, the UK political parties appeared to be competing about who could set an earlier goal. 2050 was accepted by everybody. "I think there is a sense of achievable and ambitious goal," he said.

But it would be more productive for politicians to work out how to achieve the net zero, rather than argue about the date. "We don't have a full blueprint of how we achieve net zero."

The Committee on Climate Change is "working on something much more deliberate", with a plan to publish its advice in advance of the United Nations COP (Conference of Parties) in Glasgow in November 2020. "CCS is going to feature very strongly in that work."

The main policy challenge for the UK government with carbon capture is to get started, he said. The primary obstacle in the past has been a reluctance for government to sign big cheques for large projects. So from now on, the focus will be more about supporting clusters and networks than individual projects.

Mr Stark was asked by Paul Davies, chair of the CCUS Advisory Group, how clear the intermediate milestones are between now and 2050, otherwise there is a risk "we're very busy in 2049".

Mr Stark replied that the next interim target, 57 per cent reduction by 2030, is the "last interim target that really matters. It will be a straight line to 2050."

Having carbon capture and storage plans is important to the "credibility of net zero", he said. Without CCS, "it is highly difficult to achieve. You need to make some fantastical leaps to achieve it."

There is a plan to create a "Citizen's Assembly on Climate Change", selecting 150 people, who form a representative sample of the British population, to review the options and choose which one is best for the country.

However, it may not be necessary to involve the public in carbon capture and storage discussions, he said.

The net zero question needs to be addressed "in a whole system sense", not as an argument for electricity (electrons) vs molecules (burning fuels). "We need both, we just don't know the proposition of both," he said.

Mr Stark does not believe that net zero can be achieved just through carbon pricing. While it can be an "important background factor", more measures are needed to give investors adequate reassurance, such as putting targets into law.

Mr Stark was asked if he could toughen up his message to government, on the basis that CCS can't be implemented without the public, and voters, paying one way or another, and so government will need to take tough decisions at some point. To this he simply replied "yes".

Equinor

Steinar Eikaas, vice president of low energy solutions with Equinor, gave strong arguments for why we will still need fossil fuels in a net zero era.

Europe can burn through an extra 1500 TWH of gas in a very cold winter. If this amount of energy was to be kept as back-up, that would be 200 of Norway's biggest hydro storage lakes. Or 11.6 million of Australia's 129 MWh Hornsdale Power Reserve battery storage facilities.

To build 2.5 days backup to a 360 MW wind farm, with batteries, you would need 20,000 x 20-foot box containers full of batteries, he calculates. A 1 MWH battery, equivalent to 10 Tesla cars, would provide backup for 10 seconds.

Europe's total oil and gas consumption is 8000 TWH per year. If this was to be entirely decarbonised, it would need 150 x Hinkley Point nuclear power generators making green hydrogen, plus 50,000 x 10 MW electrolysers to make hydrogen. 10 MW is the biggest electrolyser currently manufactured in the world, at a rate of 100 per year.

Alternatively, we could use 500 x 1 GW steam reformers, to convert gas to hydrogen and capture and store the carbon. 100 steam reformers of this size are currently built per year. So this is achievable with current manufacturing capacity.

We can say that renewables are perfect to decarbonize the 'easy' parts of our energy system, but there are big challenges for them to provide all our energy.

Equinor planned to start drilling (spud) the first injection well for its Norway "Northern Lights" CO2 storage project in December 2019. There were already 15 companies in 8 countries interested in providing CO2 to the scheme, as third-party customers, he said.

In terms of costs, the UK government estimates that electricity in 2035 will cost £200 per MWh, emitting 50g of CO2 per KWh. Natural gas will cost £50 per MWh emitting 200g CO2 / KWh. Hydrogen power to homes (under the H21 scheme, made from gas with CO2 sequestered) would cost £75 /MWH, with CO2 emissions of 15g / KWh. On that basis, hydrogen is slightly more expensive than gas, much less expensive than 2035 electrical power, and with lower CO2 than both.

The UK's "Zero Carbon Humber" Project, linked to the Drax power station, wants to demonstrate capture of 95 per cent of CO2, including with bio pellets combusted as a fuel, so it would be the first bioenergy carbon capture and storage plant.

"It is not going to be free," he said. There is a need for honesty about the costs. We need subsidies in one sense or another."

To illustrate, Equinor calculates that "blue hydrogen" for industrial customers, made with gas + CCS, costs 25 per cent more than "grey hydrogen," made with gas with no CCS. Heat, using blue hydrogen, would cost 50 per cent more than gas heating. Blue hydrogen power generation would be double the cost of natural gas power generation.

There is also a need to reduce the "political risk" – that a new group of politicians cancels the scheme. But one way to do it is to demonstrate that it can be done, so politicians are more confident in supporting it, he said.

Mr Eikass was criticised by one audience member for asking for subsidies as an oil company employee – while also talking about political risk. In a different context, we can say it is a massive political risk for a politician to subsidise an oil company.

"It is something we don't like. But a contribution to enable these will be required," Mr Eikass replied.

Another possible pathway is consumer choice. Will people choose to pay more for a low carbon product? If a car was made with "clean steel" (with no CO2 emitted in its production), it would add $500 to the cost of the car. But this is "a third of the cost of leather seats," another consumer option, he said.

"Let's bury the idea that CCUS is a fantasy… CCUS is absolutely essential to meet the net zero target" - Chris Stark, Committee on Climate Change Chief Executive

OGCI

Colin McGill, low carbon appraisal general manager with BP, speaking on behalf of the Oil and Gas Climate Initiative (OGCI), talked about the Clean Gas Project, an integrated CCUS project backed by OGCI Climate Investments, and with project support from BP, ENI, Equinor, Occidental Petroleum, Shell and Total.

"We're trying to build the world's first net zero industrial facility," he said.

Teesside is a relatively small industrial site, just a few kilometres wide, which made it ideal for this project, because the connections between the various facilities is much shorter. It already has a hydrogen plant. Also, it has a fertiliser plant, which generates between 500,000 and a million tonnes of pure CO2 a year.

A biomass fuelled power station is planned. If carbon capture can be added to this, it makes the investment much more worthwhile. Biomass energy costs $300 per tonne CO2 avoided, and the CCS means an extra $25 per ton CO2 avoided, but also makes the plant is net negative CO2.

The project team aim to be capturing carbon by 2025, injecting 4.5m tonnes of CO2 a year

– and by 2030 it can be a "completely decarbonised hub".

The project is "oversubscribed" by people who want to invest in it. But it needs to ensure it can "at least not lose money", he said.

Whether it is a good investment or not "is fundamentally about government policy," he said. "To invest in infrastructure, you need long term invest ability."

The planning consent documents have already been submitted, with a view to a final investment decision in early 2022, with £20m to be spent to get to that point. The next stage, Front End Engineering and Design (FEED), will cost £100m.

There will also be new regulations needed, for example for nitrosamines emission.

The project's power will come second to renewables in desirability by the National Grid.

So, the system needs to be designed for "dispatchability" – the ability to be turned on and off as its power is needed by the grid. Systems modelling work shows it may be operational 85 per cent of the time to begin with but could drop to 50 per cent as more wind power is added.

Steam is available onsite, which can bring the system's temperature up quickly, and also keep the carbon capture system running quickly.

Mitsubishi

Andrew Doyle, executive director of MUFG (Mitsubishi UFJ Financial Group), explained how the key to making a project financeable can be about reducing the risks, as much as ensuring a return.

"If you address the risks in a satisfactory manner, there's no end of liquidity. People are looking for a stable place for their money," he said.

MUFG is a Japanese bank and financial service company, which has also been involved in UK wind projects.

The UK wind sector was once considered "unbankable," due to high investor risk. But now these have been resolved, it could be considered "overbanked," he said.

"What financers look for is the main risks, who shares the risks, who bears the risks."

Mr Doyle envisages that the capture / power generation side would be a separate investment to the transport and storage side. But then you need to split out the 'chain risk', for example that problems in the capture part mean that CO2 cannot be delivered through the transport and storage system as planned, and so the transport and storage operator loses revenue.

Probably the contract would stipulate that transport and storage fees are paid whether there is CO2 or not, so it is more like a capacity payment, he said.

The CO2 capture side would also need to be insulated from the risk that the transport and storage is not available.

The income would come from the government, with a Contract for Difference agreed to offset losses incurred from the running of the carbon capture system. The costs of transport and storage can be included as part of this overall cost.

If the capture service is additionally made available to industrial users, such as steel and cement, there can be additional revenue sources. But the asset would probably be developed for the power sector first, because the Contract for Differences will be available only for power. As a "fixed component," it may be possible to get a loan against it.

For construction of the facility, an investor will want to source an Engineering / Procurement / Construction "package" which also covers the risk, he said.

The CO2 storage can be seen as a long-term liability risk, with the owners potentially liable for leaks centuries into the future. This is problematic. "There's a limited universe of bankers who take long term geology risk. [It is hard to] get people comfortable that the risk of leakage is remote." Income from CO2 storage could be outweighed by the costs of any leakage.

Having said all this, "If we can get CFD right, get the right people to take the risk, I don't see any impediment to getting this in a financeable stake," he said.

Why CCS is now different

Paul Davies, chair of the CCUS advisory group, emphasised a number of ways why the carbon capture industry is different now to how it was in 2015, when projects were cancelled.

"There will be large opportunity for investors. These are models they can engage with and understand" - Paul Davies, chair of the CCUS advisory group

Firstly, there's a commitment to net zero. "We hear the word 'essential' more and more," he said.

There's a focus on decarbonising industrial clusters, not simply looking for an "anchor project", as in 2015. Also, while renewables can replace gas and coal power, only CCS can decarbonise an industrial cluster.

There is a focus today on development of business models and making something investable. There is increased talk today about "proven technology ready to deliver at scale."

"I think that will lead to the new asset classes," he said. "There will be large opportunity for investors. These are models they can engage with and understand. The project finance approach, regulated approach."

UK Research challenge

Bryony Livesey, director of the UK Research and Innovation (UKRI) industrial decarbonisation challenge, said there is currently £170m public funding, intended to be matched by £260m of industry funding, available to "enable" the decarbonisation of UK industry.

The use of the word "enable" implies that funding from the government leads to further funding coming from industry, she said.

Up to £8m will be available for development of "industrial cluster decarbonisation roadmaps for major UK industrial clusters".

The focus will be on the social, policy and regulatory framework, rather than the technology, she said.

UK Task Force

Charlotte Morgan, partner with law firm Linklaters, talked about her work chairing the "CCUS Cost Challenge Task Force", set up by the UK government.

The group looked at better ways to encourage people to take interest as investors – if they sense there is a new "asset class" available and see a stream of business.

The Task Force discussed new commercial models designed to reduce or better manage the risk. The "Contract for Differences" model can mean a cheaper cost of debt, and so is "very popular". For a transport and storage assets, the licenses could be written to ensure a long-term revenue stream.

There is a view that electricity consumers have borne the brunt of the cost of decarbonisation to date. "We are trying to change that," she said.

The UK could receive CO_2 from other parts of Europe, brought by ship.

The CFD system is a "well known and understood mechanism", which can be used for both base load and dispatchable power. It is good to work with "what lenders know and understand."

The project team assume that industrial CCUS projects will be privately owned and financed, and probably developed in a cluster approach.

Hydrogen could be taken forward in a number of ways, including putting hydrogen into an existing gas network, or using hydrogen directly for transport.

Overall, the necessary conditions for CCUS investment are that the public recognises the central role CCUS can have in decarbonising industry, transport, heat and power, in a way other technology can't do. People need to understand the value proposition, not just see CO_2 as a problem, she said.

There needs to be a clear policy direction from the government, a clear and well understood risk allocation, clear business models with viable revenue streams, and greater clarity on costs.

DNV GL

Liv Hovem, CEO oil and gas with DNV GL, said the company predicts the percentage of fossil fuel in the energy mix will drop from 80 per cent today to 50 per cent in 2050.

DNV GL is predicting only a slow growth in carbon capture and storage up to 2035 – but then a slow rise, and a fast rise from 2040 onwards.

But by 2050, it still only anticipates 3 to 4 per cent of all CO_2 is captured. "The reason is of course the cost," she said. "We have not seen a funding [model] possible without subsidy."

One policy possibility could be to make CCS mandatory for all gas power generation – and to invest more in research and development.

Government can have strong influence on what happens – with an example being when the Norwegian government decided to increase the number of offshore wind turbines in Norway from 6 to 15, with the associated learning leading to a reduction in cost.

Ms Hovem warned that it is not yet clear that hydrogen will become the major zero CO_2 energy carrier of the future, with unanswered questions about whether people will accept it. "To make Leeds a hydrogen city in 2030 requires a lot of work and collaboration," she said.

Government push

Nick Molho, Executive Director, Aldersgate Group, noted that having a government organization managing the roll-out of a new technology can help.

He cited the example of the UK switching from "town gas" (made from coal), and coal power, to natural gas in the 1960s and 1970s. "We had the Gas Council in the UK which oversaw rollout of gas grid and central gas grid," he said. It over saw 1m houses a year converted. There were significant public concerns about safety of gas at the time.

Another way to improve roll-out of low carbon technology could be more incentives at a product level, for example a standard for building materials which shows the amount of CO_2 emitted in its manufacture. This carbon level can get tighter and tighter over time. "You create a very clear market signal, and protect domestic industry," because "imports do not comply with standard," he said.

"We need more low carbon technologies to meet the Paris Agreement and this requires strong policies" - Liv Hovem, CEO of Oil and Gas for DNV GL

For CCS to look like a success story of industrial strategy, it is important that people see that it is generating many skilled jobs for local people, he said.

In wind power, the Contract for Difference system "made a big difference to t cost of finance and overall cost of a project," he said. "We need that all round policy [in carbon capture]."

Scotland good for CCS

Mike Smith, CEO of NECCUS (North East Carbon Capture, Usage and Storage Alliance), introduced his organisation, which is a new alliance of industry, academia and government interested in CCUS and hydrogen in Scotland. It is geared to helping Scotland meet its net zero target of 2045.

He emphasized the strength Scotland has in carbon capture, including having pipelines, CO_2 storage, the right skills, manufacturing capability, CO_2 emissions from Grangemouth, and the St Fergus landing point for CO_2 pipelines.

More information

Presentations are available for online download from **www.ccusconference.org** under the tab "programme"

Offshore energy integration key to UK net zero target

Innovative partnering between oil and gas, renewables, hydrogen and carbon capture can accelerate energy transition says UK Oil and Gas Authority report.

Integrating the UK offshore energy sector, including closer links between oil and gas and renewables, can reduce carbon emissions from oil and gas production and longer term actively support delivery of the UK's net zero target through technologies such as carbon capture and storage (CCS). This is the conclusion drawn in the "UKCS Energy Integration: Interim Findings" report by the Oil and Gas Authority.

The interim report discusses the first phase of the UKCS Energy Integration project which is led by the OGA, working with BEIS, The Crown Estate and Ofgem, considering options to help feed into a new strategic vision of the UKCS as an integrated energy basin. The project is funded by a grant from the Regulators' Pioneer Fund.

The project considers how oil and gas infrastructure and capabilities can be leveraged for CCS, and to support renewable energy production and hydrogen generation, transportation and storage.

The report finds that multiple offshore integration concepts are technically feasible and would be viable options for helping to lower the oil and gas industry's carbon footprint and decarbonising the UK economy.

The report emphasises that opportunities for UKCS deployment are plentiful, diverse and location-specific. Additionally, the UK has significant wind power potential, untapped carbon storage capacity, and extensive oil and gas infrastructure in place. All the concepts discussed in the report can reduce carbon dioxide emissions but differ in terms of scalability and timeline.

The concepts discussed in the report are as follows:

• Platform electrification could significantly reduce emissions on oil and gas installations by using low-carbon electricity, including directly from offshore wind farms, to replace generation from gas and diesel. Technology for platform electrification has been proven and could enable near-term emissions reductions for the oil and gas industry.

• Gas-to-wire (GtW) may enable gas to be converted to electricity offshore and transported using existing windfarm cables. In terms of technical feasibility, individual elements are proven, but it is a niche solution suited, particularly, to the Southern North Sea (SNS) and East Irish Sea (EIS). GtW can to be combined with CCS to avoid the incremental CO2 emissions.

• CCS has already been piloted offshore and is considered essential in all UK decarbonisation scenarios, not just to decarbonise the power sector but also to enable deep cuts from other sectors, including industry. The storage potential across the UKCS and opportunity for oil and gas synergies is very significant.

• Hydrogen has feasible production avenues through both 'blue' hydrogen (produced by natural gas reforming) and 'green' hydrogen (electrolysis produced by renewables) routes, enabling decarbonisation of power, heat and transport. The offshore energy sector – both oil and gas and renewables – offer significant production, storage and transport potential, for example through the repurposing of offshore oil and gas infrastructure and offshore electrolysis, with transportation in re-used pipelines.

• Offshore energy hubs can help scaling up net-zero energy solutions, e.g. by allowing hydrogen to be generated offshore using windfarms and stored in reservoirs to be transported to shore using oil and gas infrastructure. Multiple sites across the UK would be suited to energy hubs.

The OGA said it fully supports the energy transition and welcomes the government's legally binding commitment to net zero emissions by 2050 but understands why there could be concern about UK domestic production of oil and gas in this context.

However, oil and gas will remain an important part of our energy mix for the foreseeable future, including under net zero scenarios, where the UK is still expected to be a net importer. As such, managing the declining production and maximising the economic recovery from the UK remains vital to meet those energy demands as long as they exist, and to reduce reliance on hydrocarbon imports.

"The energy transition and the UK's drive to net zero requires the oil and gas industry to embrace energy efficient operations, whilst supporting the growth of CCS, offshore renewables, and hydrogen," said Andy Samuel, Chief Executive of the OGA.

"Our report highlights the wide range and combination of solutions that can play a part, in line with the Committee for Climate Change's recommendations. Phase II is well underway, focusing on regulatory and economic aspects and we look forward to working closely with industry and government in enabling action through 2020 ahead of COP 26."

Phase 1 of the project was completed by global consultancy, Lloyd's Register (LR). Ali Kerlogue, LR's expert voice on Energy Integration said, "As an industry, the approach we're taking in developing sustainable energy sources has made significant strides in the last 12 to 18 months. The OGA's report identifies the solutions that will help drive the transition to an energy mix that embraces renewable sources using existing oil and gas infrastructure, the concepts of which can be used anywhere in the world not just the UKCS."

The OGA has appointed EY to support delivery of phase two of the project, which consists of an economic and regulatory assessment, to identify barriers, opportunities and quick-wins. The project will conclude in Q2 2020, after which a final report will be published.

More information

www.ogauthority.co.uk

Urgent action and investment needed to progress UK CCS

A comprehensive report from OGUK into the changing energy landscape has called for urgent action to progress low carbon technologies critical to the UK and Scottish Government's net zero ambitions.

The policy recommendations are published by the representative body for the oil and gas sector, OGUK, in its second Energy Transition Outlook Report. The document considers the changing energy landscape in the UK and outlines progress achieved by the UK's oil and gas sector over the past year to provide industry and economy-wide solutions towards reducing emissions.

It says government and industry must work together to progress to the next stage five key projects across the UK which look to capture, transport and store carbon dioxide from heavy emitting industrial processes including power plants. It also calls for joint action to increase the potential for low carbon hydrogen to be used as a fuel to heat homes and power cars.

However, the report authors warn that the sector will need to earn its position in the changing energy world, with rapid action required to ensure the sector transforms over the next 30 years while continuing to meet as much of the UK's oil and gas needs from domestic resources.

The report findings show:

- The UK's oil and gas industry is in a unique position to lead in the development of Carbon Capture Usage and Storage, with 5 projects situated across the country currently being explored

- UK energy sector investment will need to double in order to achieve a decarbonised economy

Commenting on the report, OGUK Chief Executive Deirdre Michie said, "Our Energy Transition Outlook report shows the changing energy landscape in the UK and the opportunities and challenges it presents all industries, businesses and people, our own included."

"With the launch of Roadmap 2035: a blueprint for net zero, we were one of the first industrial sectors to set out credible plans to support the UK and Scottish Government net zero emissions. Yet the oil and gas sector will have to earn its position in this new energy world, cutting its own emissions and working with governments and regulators to progress the five CCUS projects which now need to move forward into the next phase and developing hydrogen."

"As our report shows, there is lots of work to be done in a huge market which is only getting bigger as global demand for energy continues to grow. The Climate Change Committee report published at the beginning of this year noted CCUS was critical to our net zero ambitions. Our challenge, working with others including the OGTC's Net Zero Solutions Centre, is to realise CCUS and other low carbon technologies as an opportunity for British businesses."

More information

Download the full report at
www.oilandgasuk.co.uk

TGS sells seismic data for OGCI Teesside project

The data is to be used to verify the suitability for storage of CO2 in offshore reservoirs located in the Permian Gas Basin in the Southern North Sea. www.tgs.com

TGS has completed the sale of one of its multi-client seismic datasets to OGCI Climate Investments' Net Zero Teesside project.

Net Zero Teesside is an integrated CCUS project backed by OGCI Climate Investments, with direct project support from six of the largest oil and gas companies globally: BP, ENI, Equinor, Occidental Petroleum, Shell and Total. OGCI Climate Investments and its partners are working closely with the UK Government on a supportive policy framework to enable the UK to become a leader and exporter of CCUS technologies globally.

Colin McGill, Net Zero Teesside Project Director, said, "To be able to remove carbon dioxide emissions and store them deep underground – preventing them from being released into the atmosphere – means we need to be 100 percent sure that the reservoir chosen is fit-for-purpose. Our agreement with TGS allows us to carefully analyze the geology of the reservoirs and make the correct decisions that will sustain our CCUS operations for millennia to come."

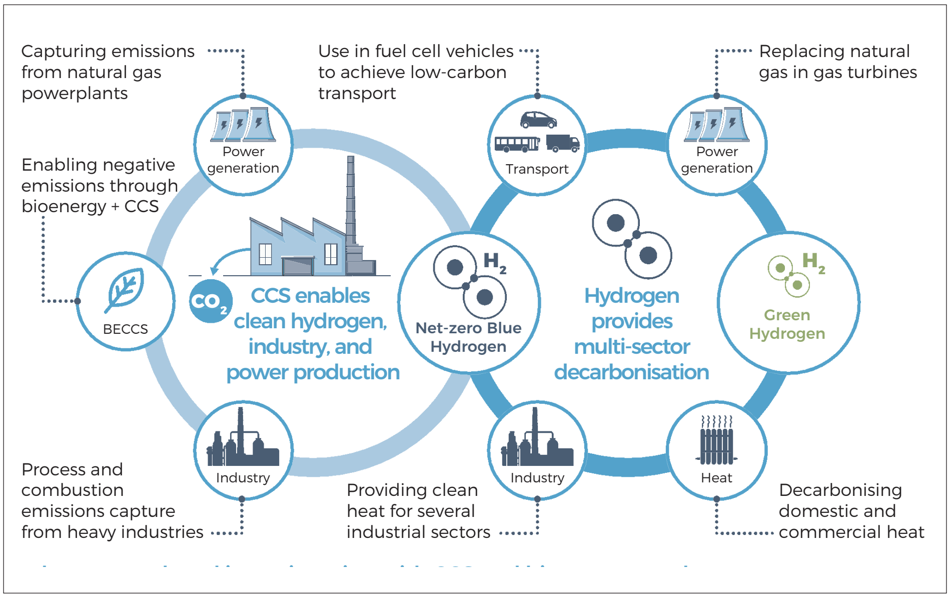
Hydrogen: enabling the UK to reach net-zero emissions

Element Energy has produced four 'Hy-Impact' reports for Equinor that outline the opportunity for hydrogen and CCS in the UK net-zero transition.

The Hy-Impact series of studies explores the technical and economic impacts of deploying hydrogen and CCS technologies in the UK. It assesses aspects from job creation to emissions reduction, and hydrogen production to its end-use, including complementing renewables in the power sector.

The studies were carried out for Equinor, a long-term energy investor in the UK in a broad range of areas and also the country's largest supplier of natural gas.

Emrah Durusut, Associate Director at Element Energy, said "The Committee on Climate Change's recent net-zero report concluded that developing CCS and low-carbon hydrogen is a necessity, not an option. I am delighted to announce the release of the Hy-Impact series of four reports, outlining the role hydrogen and CCS can play in the UK's net-zero transition".



Hydrogen, produced in conjunction with CCS and bioenergy, can be net-zero

The studies aimed to answer a number of remaining questions around hydrogen deployment in the UK and concluded that:

• Hydrogen and CCS deployment could enable over 200,000 jobs and could add £18 billion to the UK economy in 2050. Large scale hydrogen production located in industrial areas could have a positive impact on areas with high unemployment through job and value creation, whilst positioning the UK as a leader in low-carbon skills and products.

• There is sufficient bioenergy to enable net-negative hydrogen production in the UK. Blue hydrogen, which is capable of decarbonising industry, heat, transport and power, can be delivered at scale in the UK with net-zero or net-negative emissions by blending biomethane into natural gas feedstock during hydrogen production.

• Hydrogen and CCS power technologies can cost-effectively replace nuclear and unabated gas power plants. The two technologies can complement renewable electricity generation and reduce the UK electricity grid carbon intensity by up to 24% by 2035, saving 3.9 million tonnes of carbon dioxide each year.

• The Yorkshire and Humber region could represent an opportunity for development of an early hydrogen economy. Hydrogen could represent a solution for decarbonising the wider Humber region, home to the UK's largest industrial cluster by both greenhouse gas emissions and energy usage.

Plans are already developing in the UK to deploy hydrogen and CCS at scale and realise the associated benefits. For example, Drax Group, Equinor and National Grid Ventures announced the Zero Carbon Humber partnership earlier this year, aiming to deliver the UK's first zero carbon cluster in the Yorkshire and Humber region; this would help position the UK at the heart of the global energy revolution.

The proposed hydrogen demonstrator and test facility could be constructed as early as 2026, with scale-up and supply to regional end-users to follow.

"This set of reports is an important step in defining the significant contribution hydrogen and CCS can make in the delivering the UK's net-zero emissions target across several sectors. We are now working to bring this vision to reality.

Significant collaboration and investment from both the public and private sectors is essential to provide an attractive proposition for end-users and realise the emission reductions," said Steinar Eikaas, Vice President of Low Carbon Solutions at Equinor.

More information

Download the reports at
www.element-energy.co.uk

North Sea technology could play leading role in energy transition

The North Sea has the potential to become a global showcase for the energy transition as a number of low carbon solutions grow in prominence says a report from PwC and OGUK.

'Turning the Tide – the Transformation of the North Sea', shows that the North Sea can become a global leader for the energy transition through CCUS technology, aided by the alternative use of infrastructure, and the production of hydrogen.

The report, which lays out the challenges facing the North Sea as the world moves towards a low carbon future, is based on interviews with more than 20 key energy industry stakeholders. It highlights how recent changes in ownership have seen independents and private equity-backed firms gain a key position in the region.

The industry can expect to see an increased focus on innovation to drive the next wave of competitiveness given operators and service companies have perhaps cut costs as far as is sustainably possible.

This innovation in technology and business models has the potential to influence the energy transition with, in two examples, renewable energy sources set to replace gas turbines on some offshore platforms, and the geography of the basin making it ideal for offshore wind production.

CCUS could also become a major aspect of North Sea activity, with wider collaboration With extensive infrastructure already in place which could be used to store carbon dioxide through depleted oil and gas fields, the North Sea can play an important role in a technology which is seen as a way of helping to reduce carbon emissions.

Looking further ahead, the North Sea could also play a major role in hydrogen production, storage and transportation whether by converting natural gas into hydrogen or through electrolysis, using offshore wind-generated energy.

Drew Stevenson, Energy Sector Leader at PwC UK, said, "There is a necessary urgency to move to a low carbon world. As our report illustrates, there is huge potential for the North Sea to play a significant role in the energy transition, setting a precedent for facilitating the move to a clean energy future."

"The appetite exists for the North Sea energy industry to play a significant role in the transition: investor sentiment is rapidly becoming more committed to low carbon technologies while smaller exploration and production companies are looking at ways to reduce the carbon footprint of their operations. All of this creates an opportunity for the North Sea to lead the way in the energy transition."

Mike Tholen, Upstream Policy Director, OGUK, added, "The transition to a lower carbon, diverse energy mix is an exciting opportunity for our transforming industry. With extensive skills, capabilities and infrastructure, we are well placed to support the development of low carbon technologies such as CCUS and hydrogen while reducing emissions from production operations."

"Roadmap 2035: A blueprint to net zero, sets out a future vision for our industry to ensure it remains at the heart of the global energy landscape as it continues to change. Through safe, sustainable and socially accepted operations and securing government support for the delivery of the roadmap, this report underlines how the UK's offshore oil and gas industry can help unlock a fair and inclusive transition to a low carbon future."

In order for the basin to remain competitive, Turning the Tide suggests there must be an increased focus on collaboration between operators and service companies. Partnership models will be crucial to future success for both large and smaller players.

This is tied to the need for increased innovation. In a sector which has been focused on cost cutting, the reports says there now needs to be fresh solutions for driving performance.

There is widespread industry agreement that the supply chain cannot sustain further tightening and focus should instead switch to value over cost, though this will require a change in mindset among operators and services companies.

Already one of the most technologically advanced basins in the world, companies now believe it is of critical importance to share their experiences of the deployment of new technologies, as well as collaborate on developments and piloting, in order to reduce risk and time taken. There is also an increased willingness to engage more closely with the supply chain, where most new technologies are deployed.

The report also predicts that the emergence of private capital from developing countries is going to play a greater role in the funding of North Sea operators.

In 2016, PwC published Sea Change – the Future of the North Sea – which revealed how senior oil executives believed the UK Continental Shelf had a two-year window to transform itself for a productive future. Three years on and a change in ownership structure in the basin has led to smaller, agile players entering the market.

The transformation of the North Sea over the last four years has been driven by two main factors. Firstly, there have been huge cost-cutting measures put in place and this drive for efficiency continues. Secondly, a number of new players have brought more dynamism to the basin, which helped drive investment to £3.3 billion in 2018.

As major players have reduced their production footprints in the North Sea, the likes of private-equity backed Chrysaor and independents such as Spirit Energy and Enquest have increasingly taken their place.

More information

Download the full report at
www.pwc.co.uk/turningthetide
www.oilandgasuk.co.uk

Projects and policy news

A long, hard look underground is required to reach net zero says report

www.bgs.ac.uk

Advances and investment in geothermal energy, carbon capture and storage (CCS) and bioenergy with carbon capture and storage (BECCS) are "critical" to moving the UK towards its target, according to a new report published in Petroleum Geoscience.

Professor Mike Stephenson, Chief Scientist, Decarbonisation & Resource Management at BGS, said: "If we want to reach net zero by 2050, we need to focus on increasing our knowledge of the subsurface of the UK.

"Geothermal energy, carbon capture and storage and bioenergy with carbon capture and storage are the three technologies that could get the UK towards net zero.

"The Natural Environment Research Council commissioned the £31million UK Geoenergy Observatories, which are underway in Cardiff, Glasgow and Cheshire. These observatories are a huge step forwards and will help us understand the subsurface in detail that hasn't been possible before.

"We need more large-scale pilot and demonstrations of geothermal, CCS and BECCS so that we can make rapid advances in these fields."

Before meaningful progress can be made in decarbonisation and the three technologies with the most potential, Stephenson warned, scientists need to advance their understanding of the UK's subsurface.

Professor Sebastian Geiger, director of Heriot-Watt University's Institute for GeoEnergy Engineering, said: "Carbon capture and storage, combined with oil and gas production or hydrogen generation, can create almost carbon neutral energy supplies. It is an essential component to provide energy security while we transition to a low-carbon energy future.

"The North Sea industry and supply chain already has many of the technologies we need to make CCS a reality and our institute has been active in CCS research for nearly 20 years. Now what's required is large-scale demonstrations so we can build the business case for CCS.

"Energy firms around the world are committing many millions of pounds into making CCS reality, and it's essential that the UK isn't left behind."

Nick Rogers, president of the Geological Society said "Across the UK, geoscientists are working to address the challenges posed by the need to transition to low-carbon energy sources and meet UK targets for net-zero emissions.

"By bringing together knowledge of subsurface structural characteristics, fluid flow, and geochemistry, they will be able to support and drive forward efforts to ensure the energy security and independence of the UK, whilst minimising the environmental impacts of energy generation."

The new report was compiled following the 2019 Bryan Lovell conference organised by the Geological Society.

Oil and Gas Climate Initiative launches CCUS Kickstarter Initiative

oilandgasclimateinitiative.com

OGCI has launched a new initiative to unlock large-scale investment in carbon capture, use and storage (CCUS).

OGCI's CCUS KickStarter initiative is designed to help decarbonize multiple industrial hubs around the world, starting with hubs in the US, UK, Norway, the Netherlands, and China. The aim of the KickStarter is to create the necessary conditions to facilitate a commercially viable, safe and environmentally responsible CCUS industry, with an early aspiration to double the amount of carbon dioxide that is currently stored globally before 2030.

OGCI Climate Investments, OGCI's US$1 billion-plus fund, has nearly doubled the number of investments in promising clean technologies over the year. The fund now has a total of 15 investments in its portfolio. Climate Investments actively supports these companies in deployment and scale-up as well as continuing to search for additional opportunities in its focus areas.

In a joint statement, the heads of the OGCI member companies said: "We are scaling up the speed, scale, and impact of our actions in support of the Paris Agreement. Accelerating the energy transition requires sustainable, large-scale actions, different pathways and innovative technological solutions to keep global warming well below 2°C. We are committed to enhancing our efforts as a constructive partner with governments, civil society, business and other stakeholders working together to transition to a net zero economy."

OGCI also showed progress towards its methane intensity target announced last year. Members are on track to meet the methane intensity target, having reduced collective methane intensity by 9% in 2018. In addition to the methane intensity target, OGCI is now working on a carbon intensity target to reduce by 2025 the collective average carbon intensity of member companies' aggregated upstream oil and gas operations.

Additionally, all OGCI member companies have pledged to support policies that attribute an explicit or implicit value to carbon. Acknowledging the role that attributing a value to carbon plays as one of the most cost-efficient ways to achieve the low carbon transition as early as possible, OGCI supports the introduction of appropriate policies or carbon value mechanisms by governments.

IEA: Carbon capture technologies ready to make major contribution

www.iea.org

Substantial progress has been made in advancing CCUS around the world, but current trends still fall well short of what would be needed to meet global sustainable energy goals.

Global energy leaders met at an event organised by the International Energy Agency in Paris to discuss the latest developments in CCUS and identify key ways to spur near-term investment. Chaired by Ted Garrish, US Assistant Secretary, and Dr Fatih Birol, the IEA's Executive Director, the event took place ahead of the IEA's biennial Ministerial Meeting.

Today, CCUS facilities around the world are capturing more than 35 million tonnes of CO_2 per year, equivalent to the annual CO_2 emissions of Ireland. Recent announcements and commitments have the potential to more than double current global CO_2 capture capacity. But the IEA's Sustainable Development Scenario, which charts a path towards achieving the world's stated climate ambitions, calls for a 20-fold increase in annual CO_2 capture rates from power and industrial facilities in the next decade

The IEA analysis underscores the need for strengthened international partnerships for CCUS deployment that recognise the important role the technology can play across sectors and economies, and highlights the priority of developing CO_2 transport and storage infrastructure

"When we consider the scale of the energy and climate challenge, the critical importance of carbon capture is inescapable," Dr Birol said. "This meeting provides a significant opportunity to reflect on progress and determine how we can build a strong foundation for CCUS in the coming decade."

Participants in the meeting stressed that a range of technologies including CCUS is needed to bridge the gap between stated climate ambitions and energy-related CO_2 emissions while supporting energy security, energy access and economic development goals. Participants also emphasised the urgency of accelerating progress on CCUS and ensuring that the next generation of facilities in planning are able to proceed to a final investment decision.

COAL21 announces funding for Australia's first Carbon Capture Hub

www.coal21.com

Australia's largest industrial low emissions technology fund COAL21 Ltd will provide several million dollars of additional funding towards establishing Australia's first commercial scale carbon capture hub in Queensland.

COAL21 is a $550m low emission technology fund established by the Australian black coal industry with the purpose of investing in research and deployment of carbon reduction technologies. These technologies are vital to reducing the risks of human-induced climate change and will support the transition to a low emissions global economy, in line with participation in the Paris Agreement.

Through COAL21, contributors to the fund are delivering prjects which reduce and remove emissions through technology and collaboration with Australian and international partners.

The new funding will support consideration of a final investment decision in June 2020 to begin the $150 million construction of a Carbon Capture plant at the Millmerran Power Station as part of the Carbon Transport and Storage Company's Integrated Carbon Capture, Utilisation and Storage Project in the Surat Basin.

This plant – together with the further stage of geological storage – represents an estimated $230 million investment in industrially-scalable CCS in Queensland's Surat Basin, and removes some 25,000 cars equivalent of emissions every year over the project's potential 25-30 year life.

COAL21 is excited by the potential benefits from the establishment of Australia's first commercial scale carbon capture hub in Queensland. This further investment strongly aligns to COAL21's core purpose of investing in research and deployment of low emission coal technologies.

Importantly, investing in this project provides the foundation of critical infrastructure needed to reduce and remove existing and future sources of industrial emissions, including from coal-fired and other electricity generation, steel and cement manufacture, mining processes and from other future energy sources, such as hydrogen.

The investment will provide:

• an emissions reduction solution for carbon exposed industries in Southern Queensland

• better and more secure employment opportunities and improved energy security in the National Electricity Market

• the foundation of a commercially competitive emission reduction and removal solution for new high efficiency low emission power stations as well as emissions reduction infrastructure for Australian industries of the future such as hydrogen production and carbon recycling.

The Surat Basin has been chosen for its storage potential for CO_2, a range of potential commercial users of CO_2, and a number of significant industrial sources of CO_2, notably Australia's newest coal fired power stations at Millmerran, Kogan Creek and Tarong North. The Surat Basin has been consistently identified as a CO_2 storage option since 2009's National Carbon Storage Taskforce which estimated a theoretical storage capacity of up to 2.9 billion tonnes of CO_2.

Consortium studies feasibility of capturing and storing CO2 from Colorado cement plant

svanteinc.com

www.lafargeholcim.com

www.oxy.com

Svante, LafargeHolcim, Oxy Low Carbon Ventures and Total have launched a joint study to assess the viability and design of a commercial-scale carbon-capture facility at the Holcim Portland Cement Plant.

The study will evaluate the cost of the facility designed to capture up to 725,000 tonnes of carbon dioxide per year directly from the LafargeHolcim cement plant, which would be sequestered underground permanently by Occidental.

"OLCV is dedicated to advancing low-carbon solutions that will enhance Occidental's business while reducing emissions," OLCV President Richard Jackson said. "Participating in this study aligns with our goals of finding an economical pathway toward large-scale application of carbon-capture technologies to reduce emissions."

The carbon-capture facility under review will employ Svante's technology to capture carbon directly from industrial sources at half the capital cost of existing solutions. Occidental, the industry leader in CO_2 management and storage, would sequester the captured CO_2 . Pairing carbon capture from a cement plant with CO_2 sequestration is a significant step forward for the cement industry in reducing its carbon footprint.

"Being at the forefront of the low-carbon transition requires continuous innovation and partnerships," LafargeHolcim CEO Jan Jenisch said. "LafargeHolcim has significantly invested in the development of low-carbon solutions. Collaborating with Svante, OLCV and Total, we expect to realize a successful U.S. carbon-capture project in the near future."

"Svante's capital cost advantage, combined with progressive tax credit policies such as the 45Q tax credit in the U.S., can make carbon capture profitable across a range of large-scale industrial applications like cement," said Claude Letourneau, president and CEO of Svante Inc.

CATO event – big strides in Dutch CCS

The "CATO Meets the Projects 2019" forum in Utrecht on November 26 showed big strides with CCS in the Netherlands – including an update on Dutch subsidies, an operating, commercial CCS project on a waste incinerator, and a gas turbine to be converted to hydrogen. By Karl Jeffery

The "CATO Meets the Projects 2019" forum in Utrecht in November 26 reviewed developments with CCS in the Netherlands. CATO is the Dutch national R&D programme for CO2 capture, transport and storage, with around 40 partners.

We heard an update on Dutch subsidies, an update on PORTHOS and ATHOS, a 450 MW gas turbine to be converted to hydrogen, an operating, commercial CCUS project on a waste incinerator selling to greenhouses, and work to develop a new commercial stream from steelmaking waste gases, which are easier to monetise once the CO2 has been removed.

The CATO community was invited to 'Meet the Projects' at an event in November last year

Subsidies

Martijn van de Sande, advisor CCUS and geothermal at the Netherlands Enterprise Agency (RVO), gave an update on the Dutch "SDE++" (Stimulation of Sustainable Energy Transition) scheme, from the Dutch Ministry of Economic Affairs and Climate Policy.

This is an extension of scope from the "SDE+" renewables subsidy scheme, so it could cover carbon capture and storage.

SDE++ aims to compensate developers of CCS schemes for the difference between the market returns, based on carbon prices, and the development costs. So similar to the UK "Contracts for Difference" scheme. "Nothing is definite yet, work is still going on," he said.

The Dutch government have concerns about making the subsidy too big and over stimulating the market, with not much clarity yet available about CCS project development costs, he said.

The government also has concerns that requiring developers to have all the permits in place before subsidies are released may set the bar too high. This may be loosened slightly, for example to say that it may be enough for developers to say they are not aware of any potential permitting hiccups, in order to access subsidy.

But the government may also want developers to commit to paying some money if they do not manage to build the project, backed by a bank guarantee, he said.

CCUS pathways considered eligible include capture of CO2 from refineries, CCS + hydrogen production, waste incineration and steel production.

Power generation is not within the scope, on the basis that future power generation is expected to be entirely renewable. Transport and storage cannot be subsidised directly as a separate entity but subsidised as part of a CCS scheme.

There were a number of other 'innovation subsidies' issued in 2019, under the names TSE (Feasibility of large-scale industry application of CCUS), DEI+ (CCUS pilots in industry), Joint Industry Projects (JIP tender).

Also ACT (Accelerating CCS Technologies), an international scheme, where Dutch companies are involved in 6 of the 12 projects. Round 3 of ACT will start "soon" with new international collaborative projects.

There will be support for biomass energy + carbon capture and storage (BECCS) and direct air capture (DAC) projects from the beginning of 2020.

Another possible scheme is the "MMIP" - Multi annual mission orientated programs, although there is a broad set of technologies competing for the budget. "CCS is a bit less suited for this scheme," he said.

PORTHOS

Mirrijn van Eijk, stakeholder engagement manager for PORTHOS, the CCUS project in the Port of Rotterdam, said that the detailed technical work continues, mainly flow assurance and environmental impact assessment. "A lot of desk research has been done."

There are a number of companies which are considering joining the "backbone infrastructure," she said.

There will also need to be regulatory change covering both storage and utilization, she said.

The Porthos Final Investment Decision (FID) is anticipated for early 2021.

ATHOS

Thijs De Vries Thijs has a account , project director for ATHOS, and senior Business Developer at Gasunie New Energy, said that the ATHOS project has started its concept selection process, and is looking for a storage partner to accept the CO2.

It is hoped that oil and gas operators active in Netherlands waters will bid to offer CO2 storage sites. "Different partners are suitable. We want to see if there's competitiveness between them," he said.

ATHOS is similar to PORTHOS but in the Port of Amsterdam. Work on ATHOS started in early 2018.

The main source of CO2 will be Tata Steel's plant in the Port of Amsterdam. The project partners include EBN Gasunie (a Dutch natural gas infrastructure and transportation company), Tata and the Port of Amsterdam.

When asked about the biggest risks to the project going ahead, he said that it is important that PORTHOS goes ahead, since ATHOS is a follow-on project. Also, it is important that Tata is able to maintain operations in the Netherlands. (There have been big cuts in European steel making this year).

CO2 emitters should be able to seek subsidy to the cost of CCS under the SDE++ scheme, but CO2 infrastructure operators are unable to access the subsidy directly, he said.

Vattenfall

Power company Vattenfall is planning to convert a third of the power generation capacity at its Magnum power plant in Groningen, Netherlands, to run on hydrogen.

The power plant has three identical 450 MW generating blocks, and one will be converted. Vattenfall is owned by the government of Sweden.

Power generation in the Netherlands was 15 per cent renewables in 2018, but expected to rise to 65 to 70 per cent in 2030. Coal is expected to be banned, so the remaining 30-35 per cent of power will be from gas, perhaps biomass, and hydrogen.

This power generating capacity must be capable of fast start-up, so it can quickly fill the gaps between the availability of power from renewables, said Jeffery Haspels, project manager at Vattenfall.

Looking at the three options for zero CO2 power generation, the first is adding CCS on an existing power plant. This can be almost as expensive as new gas power plant, he said.

Generating power with biomass is expensive, with questions about the source of the biomass. It needs to be imported to the Netherlands, creating more CO2 emission from the ships. "Not easy," he said.

A third option is hydrogen power. The idea is that by 2030, there will be, at times, more renewable energy generated than society can immediately use, so the surplus electricity can be used to electrolyze water and make hydrogen, which is then stored, and used for power generation later. Until then, hydrogen generated from gas can be used to "kick-start a hydrogen economy".

And far in the future, in a non-fossil age, societies will have to choose between getting their renewables back-up electricity from hydrogen power, or from BECCS with CCS, he said. "We believe hydrogen is the way forward."

A hydrogen scheme may not be eligible under the SDE++ subsidy scheme, because it only covers the CCUS part of a value chain. A hydrogen chain has extra steps involved of creating and transporting hydrogen.

Hydrogen could be produced in Rotterdam, with CO2 handled via the PORTHOS system.

Gas turbine technology needs to be developed so it can combust 100 per cent hydrogen.

In terms of efficiency, a modern combined cycle gas turbine generator is 57-58 per cent efficient with natural gas, and you "lose a bit of efficiency" if the fuel is hydrogen rather than natural gas. (By comparison, a hydrogen fuel cell can be about 60 per cent efficient).

If you are making hydrogen from electrolyzing water, you can get 70 per cent efficiency from the electrolyser, so the full chain efficiency is about 40 per cent (70% x 57%).

AVR – waste management

Waste to energy company AVR has been operating a commercial carbon capture system since August 2019.

Municipal waste is incinerated, the CO2 in the flue gas is separated with an amine solvent system (MEA), and the CO2 liquefied on site and sold to Air Liquide, which then sells it to nearby industrial greenhouses as a fertilizer.

The heat from the combustion is used to run the carbon capture plant, and also sold to a nearby chemical industry customer as steam, said Hans Wassenaar, Hans has a account project manager at AVR.

The solvent is stripped of its CO2 at 120 degrees C, which fits its existing steam infrastructure.

The plant took about a year to build. It follows the operation of a test plant in 2016 at Dutch research organization TNO.

The carbon capture plant was built by a company called TPI – Techno Project Industriale. https://www.tecnoproject.com/

By the time of the conference in late November 2019, it had already captured 10,000 tonnes of CO2 over 3 months of operation. The maximum capacity is 100,000 tonnes CO2 per year, of which 60,000 tonnes could be sold to local greenhouses.

This means that the total CO2 emission from AVR's facility in Duiven is reduced by 15-20 per cent.

It can also "prove large scale installations can run, and be a basis for new projects in Netherlands," he said.

The CO2 delivered to greenhouses gets absorbed by plants, and ultimately emitted (for example by people eating the tomatoes then breathing out CO2). But it still replaces CO2 which would otherwise be created specifically for the greenhouses, so a net CO2 reduction.

In terms of costs, the capital expenditure was 20 per cent subsidized by the government. There is not much 'energy penalty' because the heat to run the capture plant is generated by the incineration of the waste.

The overall business plan is in "the lower limits of acceptable returns" to the plant owner, Mr Wassenaar said. But that still makes it commercially viable.

AVR is owned by a Hong Kong based consortium Cheung Kong Infrastructure (CKI), which saw the investment as a means to develop its own expertise on carbon capture plants, he said.

There are no CO_2 emission costs avoided, because waste incineration plants are not covered by the CO_2 Emission Trading Scheme, he said.

Monetising steel off gases

"Off gases" (exhaust) from iron and steel making contain hydrogen and methane. Jaap Vente, roadmap manager at Dutch scientific research organization TNO, has been studying if there could be a way to convert this into energy, when combined with a carbon capture process.

Once CO_2 has been removed from off gases, the concentration of hydrogen and methane in the gas stream is much higher, making it easier to monetise.

Perhaps there could be a way to convert the hydrogen and methane into methanol, DME (dimethyl ether) or Urea.

A demonstration plant is being built at Luleå, a coastal city in Sweden, handling 12 tonnes of CO_2 a day, attached to a steelworks.

The CO_2 separation process used is a Sorption Enhanced Water-Gas Shift (SEWGS) process. It was possible to recover 90 to 100 per cent of the CO_2, at 90 per cent CO_2 purity. It was also possible to capture hydrogen sulphide in the process.

The aim is to capture 100 kt per year of CO_2, and perhaps use it to make methanol, as a fuel for shipping. There is a separate plant to build a 1 tonne / day methanol plant in the region for a ferry to Kiel.

The hydrogen and nitrogen mix in the gas stream would be "perfect for ammonia".

Perhaps a quarter of the CO_2 could be used to make urea, which could be sold, paying for the capture plant. An online presentation includes further technical details.

ALIGN project

The ALIGN-CCUS project (Accelerating Low Carbon Industrial Growth through CCUS) is the largest project in the international "ACT" (Accelerating CCS Technologies) scheme, with a 21m euro budget, and 29 partners from the Netherlands, UK, Germany, Norway and Romania.

It is based around finding ways to decarbonize industrial clusters, focusing on Grangemouth and Teesside (UK), Rotterdam (Netherlands), Grenland (Norway), North Rhine Westphalia (Germany) and the Oltenia Region of Romania.

There are 6 "work projects" addressing capture, transport, storage, CO_2 re-use, industrial clusters, and society.

The storage "work project" has been developing a methodology for a standard definition of "storage readiness", he said, similar to the "technology readiness level" (TRL) scheme.

SRL1 = the first pass assessment of storage capacity at country wide or basin scales.

SRL3 = a screening study to develop an individual storage site.

SRL5 = the storage site validated by detailed analyses.

SRL7 = the storage site is permit ready or permitted

SRL9 = the storage site is on injection.

Tom Mikunda, energy consultant, noted that the UK's White Rose project took 33 months to reach SRL7, and the UK's Peterhead project took 20 months to reach the same level. This could be an indication of how long it can normally take to establish storage sites, he said.

The CO_2 re-use work project has looked at using CO_2 to develop DME dimethyl ether and OME (oxymethylene dimethyl ether) fuels, which burn cleaner than diesel, with no soot, and need only minor adjustments to a combustion engine, he said.

Pathways to hydrogen

Robert de Kler, senior Research Scientist at TNO presented work to see how a hydrogen economy can be developed.

People talk about "green hydrogen", generated with electricity from renewables electrolyzing water, and "blue hydrogen", developed from gas, but with CO_2 sequestered.

Blue hydrogen is seen as necessary to "pave the road for green hydrogen". Otherwise a hydrogen market could never develop with the initially small volumes of green hydrogen, he said.

A project is under consideration in the Port of Rotterdam, to see how well hydrogen could be used as a fuel gas for power generation and refineries.

How much storage monitoring do you need?

Filip Neele, senior scientist for CCS at TNO, has been looking at better ways to assess a monitoring plan for its effectiveness, as part of a project called PRE-ACT:

www.sintef.no/pre-act

The tasks of managing CO_2 well integrity, monitoring storage, handover of a project to another party, and decommissioning, have not yet ever been done, although they have been much thought about.

"We have a "first of a kind project" coming our way, we have to come up with a risk monitoring plan," he said.

The monitoring system needs maintain safety by making forecasts, making the forecasts more reliable, and detecting deviations from plans.

And while we know how to take measurements and do seismic surveys, we don't yet know how much and how often, and how to know if we are doing enough.

"These questions are really important for the first few projects," he said.

The planned large-scale Norwegian project Smeaheia was used as a case study.

For example, companies might want to assess the risk of CO_2 migrating from one structure to another. They can build scenarios and assess which one is most likely.

They can assess the level of uncertainty as to what is going on, and how much monitoring would help reduce the amount of uncertainty – ultimately calculating whether monitoring systems provide a return in terms of useful information.

Such efforts should prove useful in convincing regulators that a site has a good monitoring plan, he said.

More information

www.co2-cato.org/news/events

Effective carbon capture for hydrogen production

Decarbonising natural gas is essential to reach net zero targets. Adrian Finn, Process Technology Manager, Costain reviews a method that is gaining increasing recognition, that of reforming natural gas to hydrogen, and the most cost effective processes to achieve this.

To meet medium-term carbon emission targets, so as to ultimately achieve the Paris Agreement target of 100% reduction in net global emissions by 2100, the use of natural gas must continue until alternative energy sources are available. This is to ensure both reliable, low cost power and low carbon energy for industrial consumption and domestic heating. However, for natural gas to feature in the transition to zero carbon energy supplies it needs to be decarbonised. If natural gas is used directly as fuel the carbon dioxide produced by combustion needs to be captured and stored.

Decarbonisation of natural gas by reforming to hydrogen, with large-scale and relatively cost-effective carbon capture at the source of production, has significant merit and is gaining increasing recognition. Produced hydrogen can be added to natural gas with minimal changes being needed to existing gas infrastructure. Hydrogen can provide clean fuel for transportation, be used as feedstock for chemicals production and can compete with renewable power sources to generate electricity.

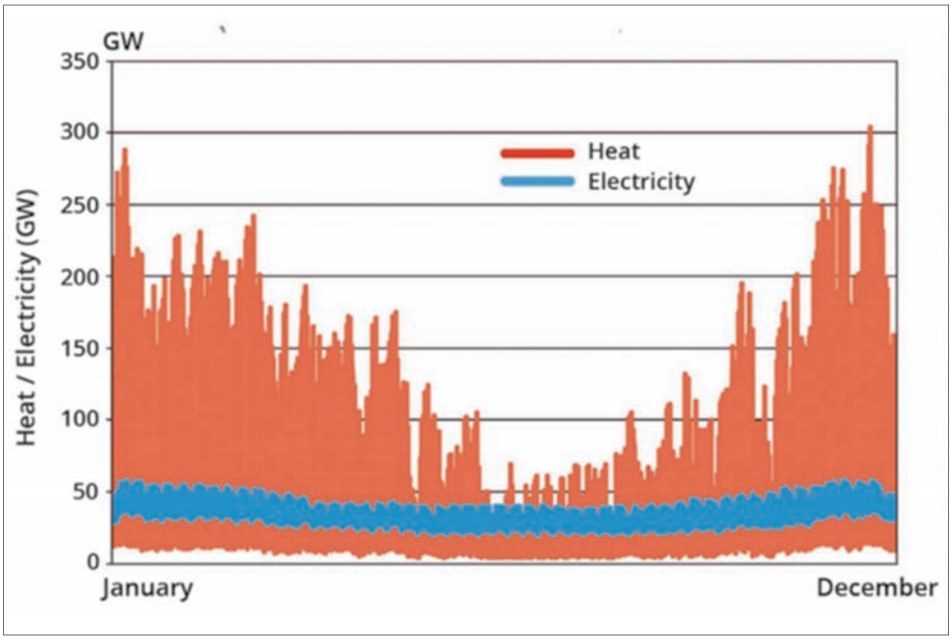


Figure 1 – UK Half Hourly Gas & Electricity Demand

Using electricity rather than natural gas would not be appropriate for provision of large-scale heating for industrial processes and domestic use. Many countries are similar to the United Kingdom (UK) in heat demand greatly outweighing electrical power demand (Figure 1). The total annual UK demand for gas and electricity in 2018 was 880 TWh and 352 TWh respectively (ref. 1) showing that decarbonisation of heating must be addressed.

Natural Gas Reforming to Hydrogen

Reforming of natural gas to produce hydrogen is the most cost-effective way to provide decarbonised heat. For the UK alone, it is estimated that over US$ 200 billion (2019 basis) will be saved by using hydrogen for heating rather than using electricity, due in large part to the existing gas infrastructure not requiring significant reinforcement (ref. 2), electrification needing storage systems and electrification leading to changes to many millions of users (as about 84% of UK homes are heated by gas). This scenario does rely on continued availability of low-cost natural gas which looks highly likely given the availability of low cost liquefied natural gas (LNG) from Qatar, Australia, Malaysia and Africa, and increasingly from the USA and Russia.

When burnt, hydrogen produces only water (other than potentially some NOx). It thus has no direct carbon burden on the environment. However, reforming of natural gas to produce hydrogen does result in formation of carbon dioxide. A typical hydrogen production plant, producing 100 kNm3/h of hydrogen emits about 2,500 tonnes per day of carbon dioxide. Therefore, effective carbon capture, at acceptable cost, is clearly critical to the take-up of hydrogen at large-scale.

The methane molecule, CH4 provides the hydrogen, H2. Whether by using steam or air or oxygen, the carbon, C, is converted to CO2, carbon dioxide. By extracting the carbon dioxide from the resultant hydrogen-rich synthesis gas ("syngas") the carbon dioxide can be captured and stored.

Hydrogen production, by high-temperature reforming with steam (Steam Methane Reforming, SMR) has been well-established for almost a century, both for the production of syngas for chemicals production and for hydrogen production for refining. Worldwide, 115 million tonnes per annum of hydrogen are produced in this way.

With SMR plants, carbon dioxide is conventionally extracted from syngas and vented to atmosphere. Hence, such hydrogen generation is a large carbon emitter. The process technologies conventionally used for carbon dioxide extraction from syngas produce low pressure carbon dioxide. This is unsuitable for storage and needs expensive processing and compression. Furthermore, with SMR up to about 40% of the natural gas is consumed as fuel. The associated CO2 emissions are in flue gas, both diluted and at low pressure, meaning that carbon capture of this carbon dioxide would be particularly expensive.

Investigations have been made of carbon capture technologies for SMR but fundamentally any carbon capture technology will be relatively expensive due to the low proportion of carbon dioxide available for capture from the syngas.

With Auto-Thermal Reforming (ATR) all the carbon dioxide from combustion ends up in the syngas (which is about 40% CO2). This is a big advantage against SMR as it enables the extraction of all carbon dioxide at process pressure, substantially improving carbon capture performance and cost-effectiveness.

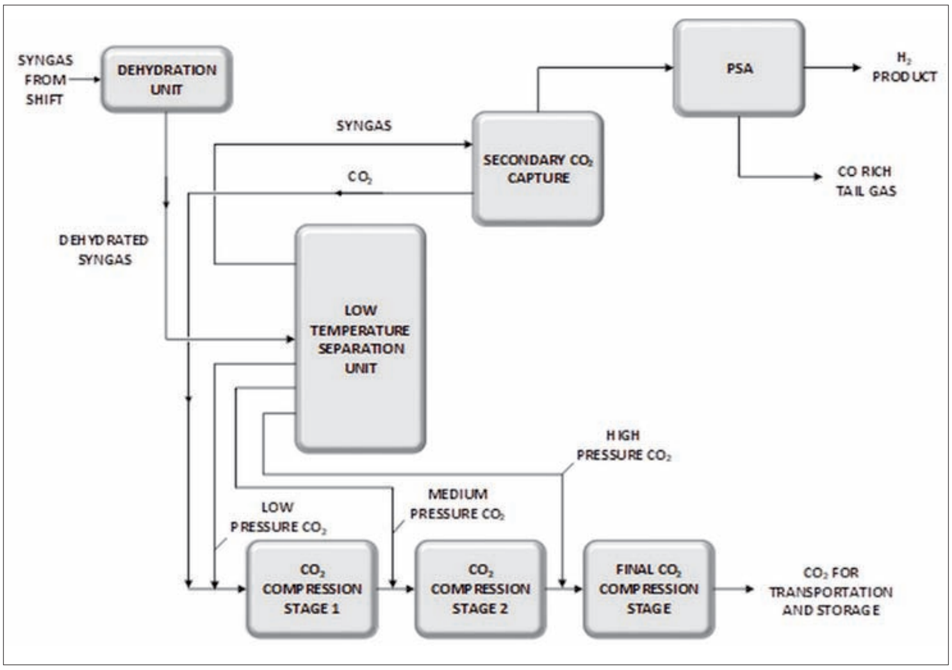


Figure 2 – Low Temperature Carbon Dioxide Capture

High reformer temperatures minimise carbon dioxide emissions. ATR is fundamentally more energy-efficient than SMR as essentially all the required heat is produced by the reforming process itself and no natural gas is used as fuel. ATR facilities can also be built at a greater scale than SMR facilities, so lowering capital cost. This has been demonstrated on several world-scale methanol, ammonia and Gas to Liquids (GTL) plants.

An even more efficient and cost-effective system than ATR couples a gas heated reformer (GHR) with an ATR reactor, as with Johnson Matthey's "Low Carbon Hydrogen" (LCH) technology. Preheated natural gas is partially reformed by steam in the GHR, prior to the ATR where it is combusted with oxygen and reformed.

Carbon emissions are minimised as the reaction energy is supplied by oxygen. This increases the natural gas efficiency compared to a basic ATR system by 6.1 %. Both ATR and LCH can significantly reduce the cost of carbon capture, LCH particularly so, as shown in Table 1.

Parameter	Units	SMR	ATR	LCH
Natural Gas as Feed	kNm^3/h	39.74	41.22	38.31
Natural Gas as Fuel	kNm^3/h	5.36	0.19	0.00
Total Natural Gas	kNm^3/h	45.10	41.41	38.31
Natural Gas Energy (LLV)	MW	439	432	400
Hydrogen Production	KNm^3/h	107.4	107.4	107.4
Hydrogen Energy (LLV)	MW	322	322	322
Natural Gas Efficiency	%	73.3	74.5	80.6
CO_2 Captured	tonnes/h	83.7	83.6	76.3
CO_2 Emitted	tonnes /h	4.4	3.1	3.7
CO_2 Captured	%	95.0	96.4	95.4
CAPEX (ISBL & OSBL)	Million US$	347	259	211

Table 1 – Comparative Performance and Cost of SMR, ATR and LCH (with thanks to Bill Cotton, Johnson Matthey)

Carbon Capture

Costain has a significant track record in hydrogen and carbon capture and has been involved with technology development, consulting, engineering, design and construction in hydrogen process plant and carbon capture technology for six decades. This includes over fifty low temperature plants for hydrogen recovery and purification.

We are working with academia and industry partners to explore relatively low cost carbon capture for large-scale hydrogen production. It transpires that carbon capture process technology developed by Costain for coal gasification syngas is the most cost-effective solution for large-scale hydrogen from reforming.

Carbon dioxide removal from gases has of course been practiced for over 100 years, with the resultant carbon dioxide conventionally sent to atmosphere. However, better capture technology is needed, that is aligned and appropriate for high pressure carbon dioxide storage. Fresh consideration of "best" capture technologies is needed.

Any proper assessment, selection and definition of process technology focusses on what the feedstock is and exactly what is ultimately wanted. In this instance, relatively pure carbon dioxide is required – pure enough to be stored. So maybe 98%+ CO2 purity is needed, the carbon dioxide to be suitably dry for storage, and preferably available from the separation process at elevated pressure, as ultimately it will be compressed to store at 120 bar or more.

The cost of boosting carbon dioxide from atmospheric pressure (as produced by most extraction technologies) to such high pressure is very significant, requiring multi-stage compression and multiple coolers. It has very high operating expenditure, OPEX, and is potentially a reliability concern, as with all rotating equipment systems. So direct production of carbon dioxide at elevated pressure is advantageous as it leads to a smaller and simpler carbon dioxide compression system and lower overall cost for carbon capture.

Carbon dioxide can and has been extracted from gas, including syngas, by various techniques – absorption in a chemical or physical solvent, adsorption and permeation through a membrane. All are reasonably suitable for ultimately venting carbon dioxide to the atmosphere but that is not the objective with carbon capture for storage.

Low Temperature Processing

The simplest way of separating any molecules is by their difference in boiling point, either by partial condensation and phase separation and/or by distillation for relatively high purity. Such systems are well-known and are relatively easy to evaluate and design by being based on such a simple principle as boiling point difference.

Of course hydrogen and carbon dioxide have widely different boiling points so hydrogen is very "light" in comparison to carbon dioxide. Thus the "relative volatility" – the measure of how light one molecule is to another – is very high for hydrogen and carbon dioxide. Separation is thus very easy.

Indeed it is so easy that just cooling, partial condensation and separation of the hydrogen-rich vapour and carbon dioxide-rich liquid is sufficient to produce carbon dioxide of sufficiently high purity for storage.

Hydrogen is produced at elevated pressure, just a little below syngas pressure. Crucially, as compared to other carbon dioxide extraction technologies, carbon dioxide can be also produced at elevated pressure, for the reasons below.

The capture process (Figure 2) operates at about -50°C. This operating temperature is achieved by refrigeration, with the refrigeration being provided by the carbon dioxide itself. There is no "external" refrigeration system or refrigeration machinery. The carbon capture plant is auto-thermal - it provides its own energy. By judiciously reducing the operating pressure of some of the carbon dioxide, it evaporates at lower temperature. This evaporating carbon dioxide now cools the feed gas to -50°C. This leads to condensation and a carbon dioxide stream containing only about 1.5% hydrogen.

Low temperature processing is widely used industrially to produce liquid nitrogen, liquid oxygen, liquefied natural gas, to extract liquids from gas (ethane, propane, butane), remove nitrogen and helium from gas and many other applications. Such plants use internal process streams to provide refrigeration as far as possible. Small temperature differences for energy transfer means they approach the ideal of thermodynamic reversibility (and minimum energy consumption) much better than alternatives. They are more energy efficient and thus require less power and/or product streams are at elevated pressure, so expensive power consumption is reduced.

Using these simple principles, Costain, with extensive experience in developing and supplying low temperature gas processing solutions, has progressed and patented process technology for carbon capture, including from syngas (ref. 3).

The relatively high processing pressure and relatively high carbon dioxide content means that carbon dioxide can be produced at elevated pressure, potentially with some as liquid. About 75% of the syngas carbon content can be removed very efficiently with the rest then being removed by downstream absorption or adsorption. If hydrogen purification is needed it is much reduced in cost and size.

Low temperature processing has been used for years for processing high carbon dioxide content gas, to produce carbon dioxide at up to 99.999% purity, suitable for use in food and drink production. The relative volatility of hydrogen to carbon dioxide is so high that a carbon dioxide purity of 98.5% is achievable just by simple vapour-liquid separation.

Higher purity can be easily attained by adding simple distillation to cost-effectively minimise hydrogen losses. The plant design is low cost, uses well-established and conventional equipment, can easily handle variations in feed gas composition and flow, has no rotating equipment and is easily scalable. It has a high Technology Readiness Level (TRL) for whatever carbon dioxide purity may be required.

Most significantly, the high energy efficiency of low temperature processing for carbon capture reduces the size and cost of downstream carbon dioxide compression by about 50% compared to conventional capture technology (that produces carbon dioxide at atmospheric pressure, or in the case of physical solvent, slightly elevated pressure). For a facility producing 500 kNm3/h of hydrogen the OPEX saving alone could be as high as US$ 200 million (2019 basis) compared to the use of alternative capture technology.

Conclusion

As hydrogen generation from natural gas reforming advances, the use of the most efficient and cost-effective available carbon capture technology (in tandem with ATR based reforming such as LCH) will help progress the journey to a net zero carbon energy future, by reducing project venture cost and especially operating cost. Low temperature carbon capture technology is available today to meet these requirements.

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2) "2050 Energy Scenarios", KPMG, July 2016

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More information

This is abridged from a paper presented at Gastech, Houston, September 18th 2019.

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Additive manufacturing of 3D ceramic structures for CO2 sorption

The 3D-CAPS project focusses on the application of 3D-printing of silica and hydrotalcites to make improved 3D-structures for the sorption of CO2 from industrial (off-)gases.
By Hans Willemsen, 3D-CAT, and Robert de Boer, TNO

Additive Manufacturing (AM) of ceramic structures will enable complex design of sorbents and catalysts with improved operational performance in various areas. AM technologies like 3D-printing have several advantages compared to current subtractive manufacturing technologies, but also come with challenges like proper ceramic paste preparation and skillful post-processing like de-binding and sintering.

AM ceramic structures applied in the chemical industry promise better mass transfer, pressure drop, heat exchange, selectivity, flexible form factors, recyclability, safety, change out time, start/stop, albeit at a higher cost, compared with packed bed reactors, and similar advantages (except pressure drop) compared with honey comb structures. These advertised improvements imply that smaller and less expensive plant (on a life-cycle basis) are possible. The purpose of the 3D-CAPS project is to investigate what reduction in size is possible for a sorbent process (with the same throughput).

Some theoretical work has been done to explain why it is plausible that a plant based on AM structures could be 10x smaller, compared with traditional packed-bed reactors, with the same production capacity, along the following lines (Fig. 1), where:

P: traditional packed bed

M1: traditional monolith

M2: same monolith, but with 2x the flow of reactants

B: printed monolith, but with 10x the flow, distributed input of gases, and integrated heat extraction. The red points show the position in the reactor when 90% conversion is reached.

Then we need to look at pairs of reactors for comparison.

P->M1: because of the much narrower range of times for which the gas remains in the reactor (the residence distribution), the monolith achieves 90% conversion at 45% of the reactor length, compared to the packed-bed that requires 72% of the bed. The monolith also has the advantage of a much smaller pressure drop.

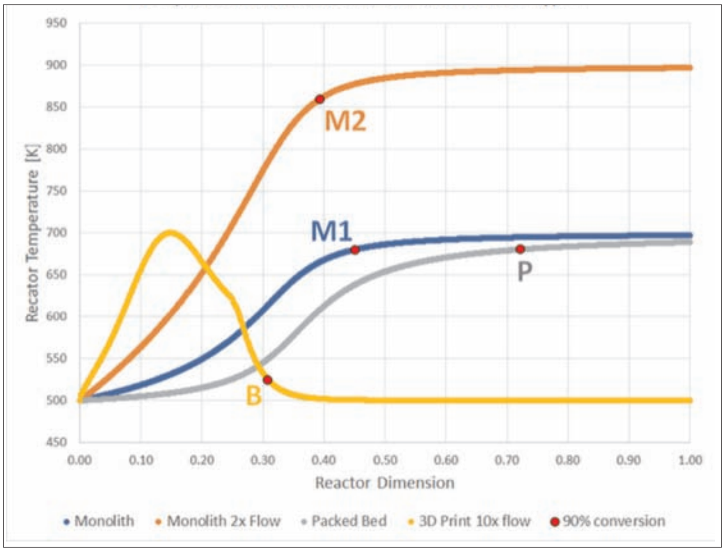


Figure 1 - Temperature and conversion different reactor types

M1->M2: the amount of gas to be processed is double, i.e. its flow rate. This leads to a much higher exit temperature of the bed (twice the temperature increase for M1). Note the 90% conversion is reached quicker (at 39% of reactor length) even though more must be processed because the average bed temperature is higher, which gives a higher reaction rate. The reason not to increase the flow rate even more, is because the temperature will eventually lead to several problems - integrity of the catalyst, and cost of reactors being the most important.

M2->B: This 3d-printed reactor is designed such that the flow is distributed along the first 20% of the reactor, and that heat is extracted along the hole of the reactor. The flow is 5x larger than M2, and even 10x larger than M1. The integrated heat function and distribution of incoming gases causes the 90% conversion to be reached at already 31% of the reactor length.

B->P: the flow in the 3d-printed reactor is 10x higher than the packed bed, and the 90% conversion is hit at 31% of the reactor length, compared to 72% of the reactor length. In this case the performance is thus 23x better.

Caveats: this is a very simple (excel) model of a reaction, and of the difference in residence times between a packed-bed and a monolith, we have chosen a distribution between these too as the 3d-printed bed. To be sure, we do not yet know, how we will integrate the distribution of incoming gas along the reactor length, or how we will integrate the heat extraction, but these things should be possible if we can print any shape we like in multiple materials.

Application improvement area 1: sorbents

The petrochemical industry, like other industries such as power plants and steel companies, have used amine solutions (like MEA, DEA and MDEA) to remove CO2 from industrial (off-)gases for a long time. In these processes, the gas stream that has to be treated is passed through a column filled with amine solution. The CO2 reacts with the amine and stays behind in the solution, which is regenerated in a parallel column.

This process is applied in hundreds of plants in the world but has its challenges as well. First of all, the amine solutions will gradually contaminate due to e.g. sulfur containing trace components in the gas stream. In addition, the solution degrades over time due to the inherent process conditions. Finally, these are not simple (from a process control point of view) operations that also require tall columns, effectively making it expensive and difficult to apply in e.g. off-shore applications.

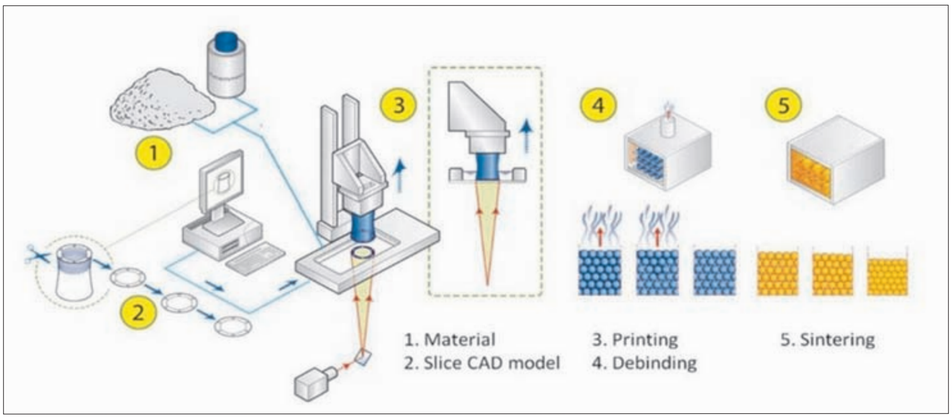


Figure 2 - Overview of the Digital Light Processing (DLP) additive manufacturing process

Application improvement area 2: catalysts

The petrochemical industry (i.e. refineries, chemical plants) has been using heterogeneous catalysts (e.g. ceramic particles loaded with precious metal) to accelerate most of their chemical conversions processes for many decades. The catalyst particles are deposited in a reactor vessel or column for a period of say 5 years. The reactants are entered from one end, and the products are exited from the other end. If heat is needed or generated in the conversion process, it can be supplied or removed via the wall of the vessel, via the entering reactants or exiting products, or via an inserted pipe system.

This proven technology has several areas of inherent improvement. During the deposition process, but certainly during the 5-year operating period, maldistribution of the catalyst particles may occur, due to pressure shocks and flow deviations. This in turn may lead to a maldistribution of the reactant flow through the reactor, that may lead to unwanted temperature differences over the reactor, with (in the case of exothermal reactions) hot spots as a result. These hot spots may lead to co-sintering of catalyst particles, which aggravate mentioned maldistribution, and may complicate catalyst removal during the next shutdown.

In addition, the heat supply or removal via an inserted pipe system is troublesome, as extreme reaction conditions may lead to corrosion, and the presence of the catalyst particles to erosion of the pipes.

Finally, the catalysts particles themselves may erode during deposition and during service, which leads to reactant flow maldistribution due to clogging caused by different particle sizes and fines generated.

Solutions

a) Current

Industry nowadays are using structures to generate improvements, in catalytic and especially in sorbent applications.

However, these products are predominantly made from metal, which implies that several problems are not addressed, including footprint and size.

b) AM

With the advent of Additive Manufacturing (AM) technologies like 3D-printing, it has become possible to make tailor made structures of ceramic materials that can help address abovementioned improvement areas.

AM structure design is done with appropriate simulation and design programs, which produce a digital file of horizontal slices from the envisaged 3D-structure. These data are transferred to the AM machine of choice, and the structure is subsequently produced pixel by pixel and layer by layer. A typical resolution is around 20 micrometer.

Compared to traditional subtractive manufacturing technologies, AM enables complex 3D structures that amongst others will integrate mixing, optimize throughput, reduce pressure drop and increase heat exchange.

Properly applied and combined, these improvements will result in more complex but more integrated sorption and catalytic 3D structures and installations, that in turn will be smaller, lighter and more energy efficient. Consequently, petrochemical plant will be cheaper to build (capex) and operate (opex).

In addition, the potential smaller size and lower weight will enable installation of e.g. (CO_2) sorption units where space and weight come at a premium, like off-shore production platforms.

AM challenges

Whilst AM has a large potential, there are challenges with these manufacturing technologies as well. The chain to AM-produce 3D ceramic structures has the following components:

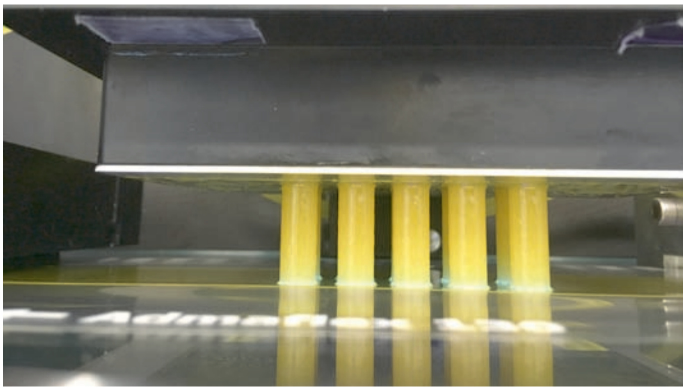
1. starting material prep → 2. AM manufacturing → 3. de-binding → 4. sintering

1. The choice of ceramic material, particle size distribution and choice of binder are essential to achieve the right final product properties

2. There are several AM technologies available for ceramics nowadays, like DLP (digital light processing and FFF (fused filament fabrication) (both variants of ceramic 3D-printing) and co-sintering technologies. The most commonly used technology is DLP (Fig. 2).

The choice of which AM method to use to make a certain product depends on a) the choice of starting material and b) the required properties (e.g. structural strength and surface porosity) of the product. As a consequence, in various occasions producers for example opt for surface treatment before or after sintering.

3. The de-binding in step 3 is important from an operational point of view, as too fast temperature increases of the green product will lead to micro-cracks.



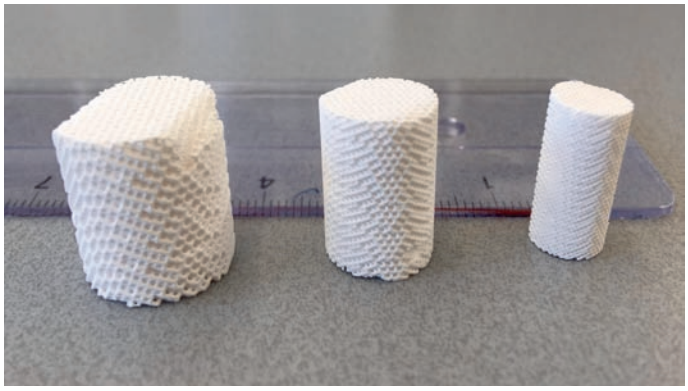


Figure 3 – The 3D-Caps printing process (left) and the resulting development product (Images: TNO)

4. Finally, the sintering step is crucial for the final strength and dimensions of the product. This finishing is sometimes more governed by art than by science, (operator skills/ experience).

All 4 steps have an influence on the characteristics of the final 3D structure, like strength, surface porosity etcetera, so knowledge about the impact and control of each step, as well as the overall integration of them, is essential to achieve a satisfactory final product.

AM next steps

For the proper application of these 3D-structures to sorbents and catalysts, the optimal design of the 3D-structure itself with respect to flow/throughput optimization, pressure drop reduction and maximum heat exchange surface at the right locations is very important. In other words: before the 3D slice file can be made to manufacture the structure, there will be various complicated computational flow dynamics (CFD) runs and iterations, to optimize the structure for its ultimate application.

The currently running ACT 3D-CAPS project is a good example, as it aims to optimize, design and manufacture (via 3D-printing) structured sorbents from various starting materials like silica and hydrotalcite to remove CO2 from industrial (off-) gases in a much more efficient way than current solvent technologies.

Other similar technology development and demonstration projects are currently starting (e.g. ZEOCAT-3D (A H2020 project), to manufacture optimized AM produced zeolytic catalysts), and under development.

Such projects are important to gather enough evidence that AM production of 3D-structures for sorption and catalysis indeed bring about a disruptive reliable step change that will convince industry to start to embrace this promising new route to sorbents and catalysts.

More information

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Capture and utilisation news

New material design tops carbon capture from wet flue gases

actu.epfl.ch

Chemical engineers at EPFL have designed a material that can capture CO2 from wet flue gasses better than current commercial materials. The work is published in Nature.

Metal Organic Frameworks (MOFs) are among the most promising of these materials, but most of these materials require drying the "wet" flue gas first, which is technically feasible but also very expensive – and thus less likely to be implemented commercially.

In a strange twist of nature – or design chemistry – materials that are good at capturing CO2 have proven to be even better at capturing water, which renders them of little use with wet flue gasses. It seems that in most of these materials, CO2 and water compete for the same adsorption sites – the areas in the material's structure that actually capture the target molecule.

Now, a team of scientists led by Berend Smit at EPFL Valais Wallis have designed a new material that prevents this competition, is not affected by water, and can capture CO2 out of wet flue gases more efficiently than even commercial materials.

In what Smit calls "a breakthrough for computational materials design", the scientists used an out-of-the-box approach to overcome the difficulties presented with material design: the tools of drug discovery.

When pharmaceutical companies search for a new drug candidate, they first test millions of molecules to see which ones will bind to a target protein that is related to the disease in question. The ones that do are then compared to determine what structural properties they share in common. A common motif is established, and that forms the basis for designing and synthesizing actual drug molecules.

Using this approach, the EPFL scientists computer-generated 325,000 materials whose common motif is the ability to bind CO2. All the materials belong to the family of MOFs – popular and versatile materials that Smit's research has been leading the charge on for years.

To narrow down the selection, the scientists then looked for common structural motifs among the MOFs that can bind CO_2 very well but not water. This subclass was then further narrowed down by adding parameters of selectivity and efficiency, until the researchers' MOF-generation algorithm finally settled on 35 materials that show better CO_2 capturing ability from wet flue-gas than current materials that are commercially available.

"What makes this work stand out is that we were also able to synthesize these materials," says Smit. "That allowed us to work with our colleagues to show that the MOFs actually adsorb CO_2 and not water, actually test them for carbon capture, and compare them with existing commercial materials." This part of the study was carried out in collaboration with the University of California Berkeley, the University of Ottawa, Heriot-Watt University and the Universidad de Granada.

"The experiments carried out in Berkeley showed that all our predictions were correct," says Smit. "The group in Heriot-Watt showed that our designed materials can capture carbon dioxide from wet flue gasses better than the commercial materials.

Capturing CO2 from trucks and reducing their emissions by 90%

www.epfl.ch/labs/ipese

Researchers at EPFL have patented a new concept that could cut trucks' CO_2 emissions by almost 90%.

Researchers at EPFL have come up with a novel solution: capturing CO_2 directly in the trucks' exhaust system and liquefying it in a box on the vehicle's roof. The liquid CO_2 is then delivered to a service station, where it is turned into conventional fuel using renewable energy.

The project is being coordinated by the Industrial Process and Energy Systems Engineering group, led by François Maréchal, at EPFL's School of Engineering. The patented concept is the subject of a paper published in Frontiers in Energy Research.

Scientists propose to combine several technologies developed at EPFL to capture CO_2 and convert it from a gas to a liquid in a process that recovers most of energy available onboard, such as heat from the engine. In their study, the scientists used the example of a delivery truck.

First, the vehicle's flue gases in the exhaust pipe are cooled down and the water is separated from the gases. CO_2 is isolated from the other gases (nitrogen and oxygen) with a temperature swing adsorption system, using metal-organic frameworks (MOFs) adsorbent, which are specially designed to absorb CO_2.

Those materials are being developed by the Energypolis team at EPFL Valais Wallis, led by Wendy Queen.

Once the material is saturated with CO_2, it is heated so that pure CO_2 can be extracted from it. High speed turbocompressors developed by Jürg Schiffmann's laboratory at EPFL's Neuchâtel campus use heat from the vehicle's engine to compress the extracted CO_2 and turn it into a liquid. That liquid is stored in a tank and can then be converted back into conventional fuel at the service stations using renewable electricity. "The truck simply deposits the liquid when filling up with fuel," says Maréchal.

The whole process takes place within a capsule measuring 2 m x 0.9 m x 1.2 m, placed above the driver's cabin. "The weight of the capsule and the tank is only 7% of the vehicle's payload," adds Maréchal.

"The process itself uses little energy, because all of its stages have been optimized."

The researchers' calculations show that a truck using 1 kg of conventional fuel could produce 3kg of liquid CO_2, and that the conversion does not involve any energy penalty.

Only 10% of the CO_2 emissions cannot be recycled, and the researchers propose to offset that using biomass.

Transport and storage news

decarbonICE - creating a pathway to carbon negative shipping

www.decarbonice.org

The shipping industry is looking for carbon free solutions to achieve the IMO 2050 target of a 50% CO_2 emissions reduction compared to the 2008 level.

A group of leading shipping companies including NYK, Sovcomflot, Knutsen OAS and Ardmore, ship builders, including DSME and the mining company Vale, have teamed up with Denmark based Maritime Development Center to develop an on-board carbon capture and storage solution in a project named decarbonICE.

"While we support a final goal of availability of zero carbon or carbon neutral fuels, we believe that a bridging carbon free solution is needed, which can utilize existing assets in terms of ships, propulsion systems and fuels. The decarbonICE project is intended to offer exactly that, and at a predicted low energy penalty well below 10%," says the Chairman of the decarbonICE project, former DNVGL President and CEO Henrik O. Madsen.

DecarbonICE is based on two new main ideas for the capture and storage part, respectively. The CO_2 and other GHG's in the ship exhaust are captured on board in a cryogenic process and turned into dry ice. Proven offshore technology is then applied during normal ship operations to transport the dry ice into the seafloor sediments. Here the CO_2 will be safely and permanently stored as liquid CO_2 and CO_2 hydrate.

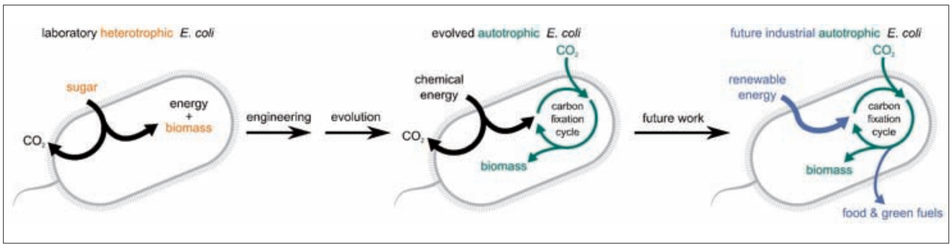
The decarbonICE concept is intended for ship newbuildings, but also for retrofitting on existing ships, thereby providing the opportunity to accelerate the transition towards the IMO target. In combination with future carbon neutral fuels like biofuels and electro fuels, the decarbonICE technology can create carbon negative shipping and thus contribute to atmospheric carbon reduction at a significantly lower cost than shore-based CCS.

"The maritime industry seems to be overlooking that on-board carbon capture with subsequent storage at appropriate sites may also qualify as a carbon free solution. At DSME we are following several Korean research groups studying the behavior of CO_2 injected into seabed sediments. The success of the decarbonICE project will also depend on how the required power can be minimized for the cryogenic cooling process," says Mr. Odin KWON, CTO of DSME.

The project started 1 October 2019 and will run through 2020. The aim is to prepare a feasibility study and to initiate the IMO approval process for the technology.

CO2 eating bacteria could produce biofuels from air

Bacteria at the Weizmann institute can exist solely on CO2 from air, pointing the way to the potential of carbon negative biofuels.



Researchers converted the common lab, sugar-eating (heterotrophic) E. coli bacterium (left) to producing all of its biomass from CO2 (autotrophic), using metabolic engineering combined with lab evolution. The new bacterium (center) uses the compound formate as a form of chemical energy to drive CO2 fixation by a synthetic metabolic pathway. The bacterium may provide the infrastructure for the future renewable production of food and green fuels (right)

Bacteria in the lab of Prof. Ron Milo of the Weizmann Institute of Science have not just sworn off sugar – they have stopped eating all of their normal solid food, existing instead on carbon dioxide (CO2) from their environment. That is, they were able to build all of their biomass from air. This feat, which involved nearly a decade of rational design, genetic engineering and a sped-up version of evolution in the lab, was reported this week in Cell. The findings point to means of developing, in the future, carbon-neutral fuels.

The study began by identifying crucial genes for the process of carbon fixation – the way plants take carbon from CO2 for the purpose of turning it into such biological molecules as protein, DNA, etc. The research team added and rewired the needed genes. They found that many of the "parts" for the machinery that were already present in the bacterial genome could be used as is. They also inserted a gene that allowed the bacteria to get energy from a readily available substance called formate that can be produced directly from electricity and air and which is apt to "give up" electrons to the bacteria.

Just giving the bacteria the "means of production" was not enough, it turned out, for them to make the switch. There was still a need for another trick to get the bacteria to use this machinery properly, and this involved a delicate balancing act. Together with Roee Ben-Nissan, Yinon Bar-On and other members of Milo's team in the Institute's Plant and Environmental Sciences Department, Gleizer used lab evolution, as the technique is known; in essence, the bacteria were gradually weaned off the sugar they were used to eating.

At each stage, cultured bacteria were given just enough sugar to keep them from complete starvation, as well as plenty of CO2 and formate. As some "learned" to develop a taste for CO2 (giving them an evolutionary edge over those that stuck to sugar), their descendants were given less and less sugar until after about a year of adapting to the new diet some of them eventually made the complete switch, living and multiplying in an environment that served up pure CO2.

To check whether the bacteria were not somehow "snacking" on other nutrients, some of the evolved E. coli were fed CO2 containing a heavy isotope – C13. Then the bacterial body parts were weighed, and the weight they had gained checked against the mass that would be added from eating the heavier version of carbon. The analysis showed the carbon atoms in the body of the bacteria were all extracted directly from CO2 alone.

The research team then set out to characterize the newly-evolved bacteria. What changes were essential to adapting to this new diet? While some of the genetic changes they identified may have been tied to surviving hunger, others appeared to regulate the synchronization of the steps of making building blocks through accumulation from CO2.

"The cell needs to balance between toxic congestion and bankruptcy," says Bar-On. Yet other changes the team noted had to do with transcription – regulating how existing genes are turned on and off. "Further research will hopefully uncover exactly how these genes have adjusted their activities," says Ben-Nissan.

The researchers believe that the bacteria's new "health kick" could ultimately be healthy for the planet. Milo points out that today, biotech companies use cell cultures to produce commodity chemicals. Such cells – yeast or bacteria – could be induced to live on a diet of CO2 and renewable electricity, and thus be weaned from the large amounts of corn syrup they live on today.

Bacteria could be further adapted so that rather than taking their energy from a substance such as formate, they might be able to get it straight up -- say electrons from a solar collector – and then store that energy for later use as fuel in the form of carbon fixed in their cells. Such fuel would be carbon-neutral if the source of its carbon was atmospheric CO2.

"Our lab was the first to pursue the idea of changing the diet of a normal heterotroph (one that eats organic substances) to convert it to autotrophism ('living on air')," says Milo. "It sounded impossible at first, but it has taught us numerous lessons along the way, and in the end we showed it indeed can be done. Our findings are a significant milestone toward our goal of efficient, green scientific applications."

Prof. Ron Milo is the Head of the Mary and Tom Beck - Canadian Center for Alternative Energy Research.

More information

www.weizmann.ac.il/plants/Milo

Study shows world has sufficient CO2 storage capacity

The study concludes there is easily enough space in the world's nearshore continental margins to meet the IPCC's goal of storing 6 to 7 gigatons of carbon dioxide a year by 2050.

The study - from The University of Texas at Austin, the Norwegian University of Science and Technology and the Equinor Research Centre - looks at the amount of geological space available in formations that is likely suitable to hold greenhouse gas emissions, keeping them from the atmosphere. It also calculates the number of wells needed worldwide to reach the IPCC's 2050 goal.

The United Nation's Intergovernmental Panel on Climate Change (IPCC) has stated that CCS needs to achieve 13% of the world's necessary emission reductions by 2050. Some policy-makers, industry representatives and non-government organizations are dubious that CCS can meet its portion of the goal, but the new study published in Nature Scientific Reports shows that CCS could achieve its targets.

"With this paper, we provide an actionable, detailed pathway for CCS to meet the goals," said coauthor Tip Meckel of UT's Bureau of Economic Geology. "This is a really big hammer that we can deploy right now to put a dent in our emissions profile."

It concludes there is easily enough space in the word's nearshore continental margins to meet the IPCC's goal of storing 6 to 7 gigatons of carbon dioxide a year by 2050, and that the goal could be achieved by installing 10,000 to 14,000 injection wells worldwide in the next 30 years.

"The great thing about this study is that we have inverted the decarbonization challenge by working out how many wells are needed to achieve emissions cuts under the 2-degree (Celsius) scenario," said lead author Philip Ringrose, an adjunct professor at the Norwegian University of Science and Technology.

"It turns out to be only a fraction of the historical petroleum industry - or around 12,000 wells globally. Shared among 5-7 continental CCS hubs - that is only about 2,000 wells per region. Very doable! But we need to get cracking as soon as possible."

Pressure, not volume, the deciding factor

The authors first looked at continental shelves worldwide to get a sense of how much capacity there would be to store carbon dioxide.

Previous studies of how much storage would be available offshore have mainly looked at estimated volumes in different rock formations on the continental shelf. The authors argue, however, that the ability of the rock formation to handle pressure is more important in figuring out where CO2 can be safely stored.

That's because injecting CO2 into a rock formation will increase the pressure in the formation. If the pressures exceed what the formation can safely handle, it could develop cracks that would require early closure of projects.

Given that assumption, the researchers developed a way to classify different storage formations according to their ability to store CO2. Under this approach, Class A formations are those without significant pressure limits, and thus the easiest to use, while Class B formations are those where CO2 can be injected into the system up to a certain limit, and Class C formations are those where pressures will have to be actively managed to allow the CO2 to be injected.

"We argue that this transition from early use of CO2 injection into aquifers without significant pressure limits (Class A), through to CO2 storage in pressure-limited aquifers (Class B) and eventually to pressure management at the basin scale (Class C), represents a global technology development strategy for storage which is analogous to the historic oil and gas production strategy," the researchers wrote.

Essentially, the authors say, as experience with injecting CO2 into offshore formations grows, the ability to use the Class B and C areas will improve, much as geologists and petroleum engineers have gotten better over the decades at extracting hydrocarbons from more and more challenging offshore formations.

Can we drill fast enough?

It's one thing to have enough space to store CO2 — you also have to inject it into the storage formations fast enough to meet the IPCC estimates of 6 to 7 gigatons of carbon dioxide a year by 2050.

By comparison, "Four existing large-scale projects inject 4 million tonnes CO2 per year. If all 19 large-scale CCS facilities in operation together with a further 4 under construction are considered, they will have an installed capture capacity of 36 million tonnes per year," the researchers wrote. This is clearly not enough, since a gigatonne is 1,000 million tonnes.ic way of going after this."

Nevertheless, the history of the oil and gas industry suggests that ramping up the technology and infrastructure required to reach the IPCC target by 2050 is very doable, the researchers wrote. Assuming an average injection rate per well, they calculated that more than 10000 CO2 wells would need to be operating worldwide by 2050.

While this may seem like an enormous number, it's equivalent to what has been developed in the Gulf of Mexico over the last 70 years, or five times what has been developed by Norwegians in the North Sea.

"Using this analysis, it is clear that the required well rate for realizing global CCS in the 2020–2050 timeframe is a manageable fraction of the historical well rate deployed from historic petroleum exploitation activities," the researchers wrote.

"With this paper, we provide an actionable, detailed pathway for CCS to meet the goals," Meckel said. "This is a really big hammer that we can deploy right now to put a dent in our emissions profile."

More information

norwegianscitechnews.com

- CATO event – big strides in Dutch CCS
- An operating, commercial CCS project on a waste incinerator
- Updates on PORTHOS and ATHOS